Whist Lab

Laboratoire commun de l'Institut Télécom et de Orange Labs

Contribution of Statistics to Human Exposure Assessment

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Orange Labs & Whist Lab

Mascot Num 2014

ETH Zurich 2014 April 25th

Groupement de Recherche MASCOT-NUM

Méthodes d'Analyse Stochastique pour les COdes et Traitements NUMériques

Institut Télécom orange

outline

Wireless communication today

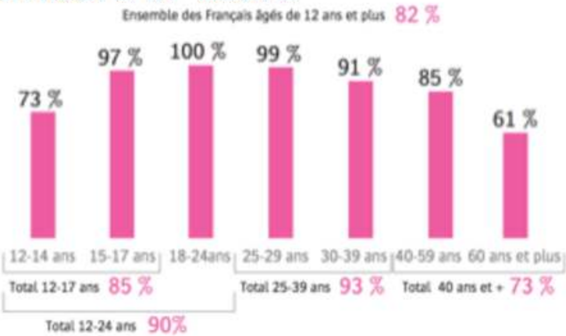
Determinist approach of Exposure and EMF

The challenge of the variablility for EMF

Surrogate models in EMF exposure assessement

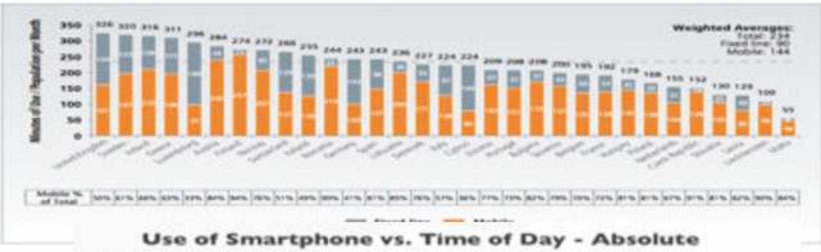
Intensive use of wireless communication systems

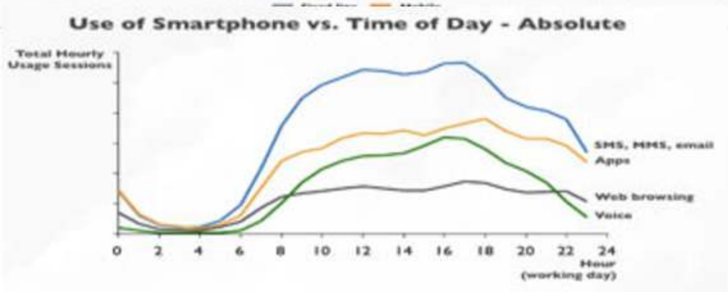
- Large numbers of users



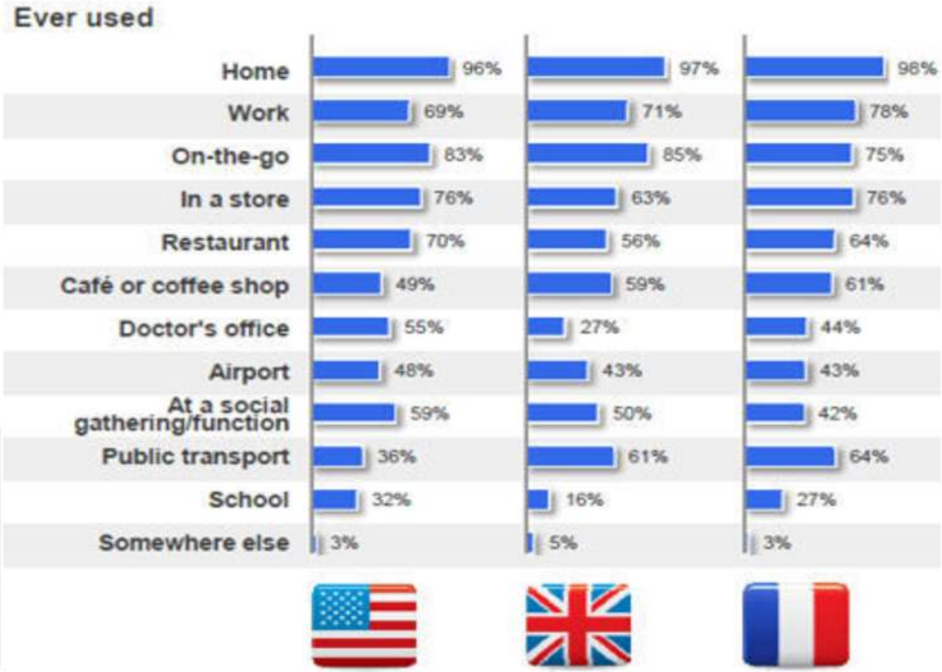
% of French people using a mobile by category of age

- Larger and larger duration of use





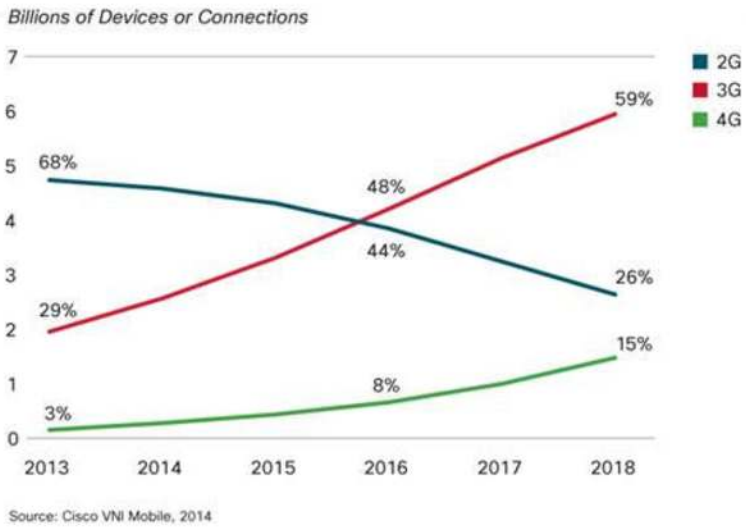
- versatile use
  - IPSOS pooling in 2012

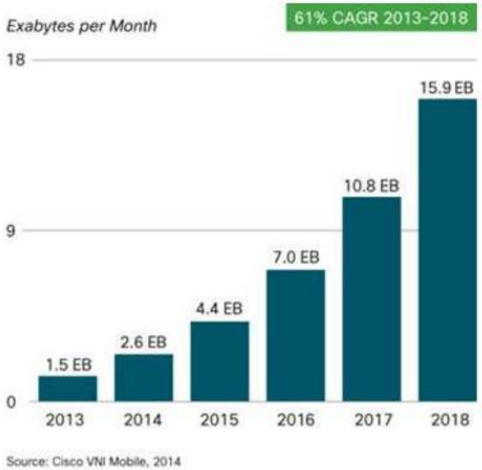


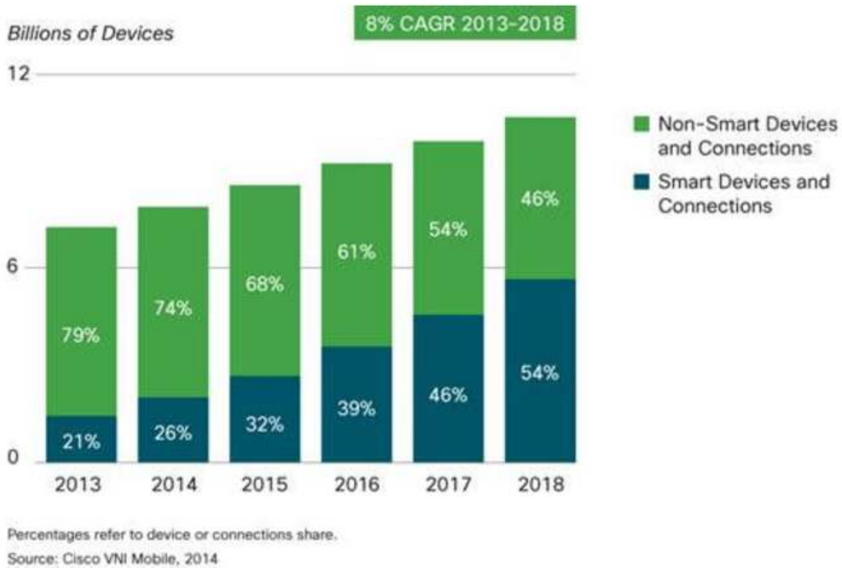
internet mobile:
2011: 189 Mo per month.
2012 342 Mo per month

Wireless Communication: Trends

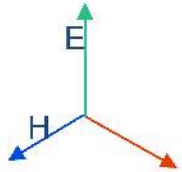
- Data exchange increase
- Networks evolve







Electromagnetic Fields (EMF) and Wireless

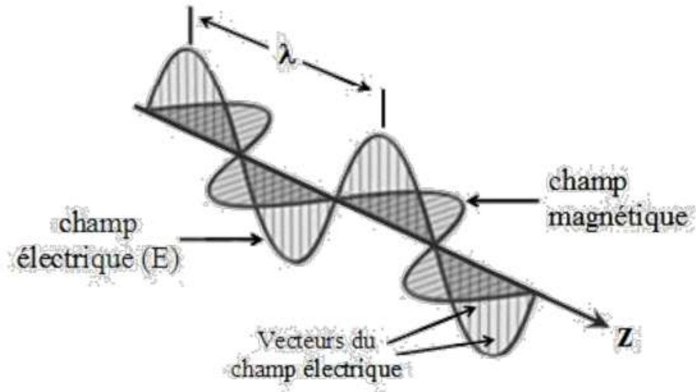


EMF Wave is composed of

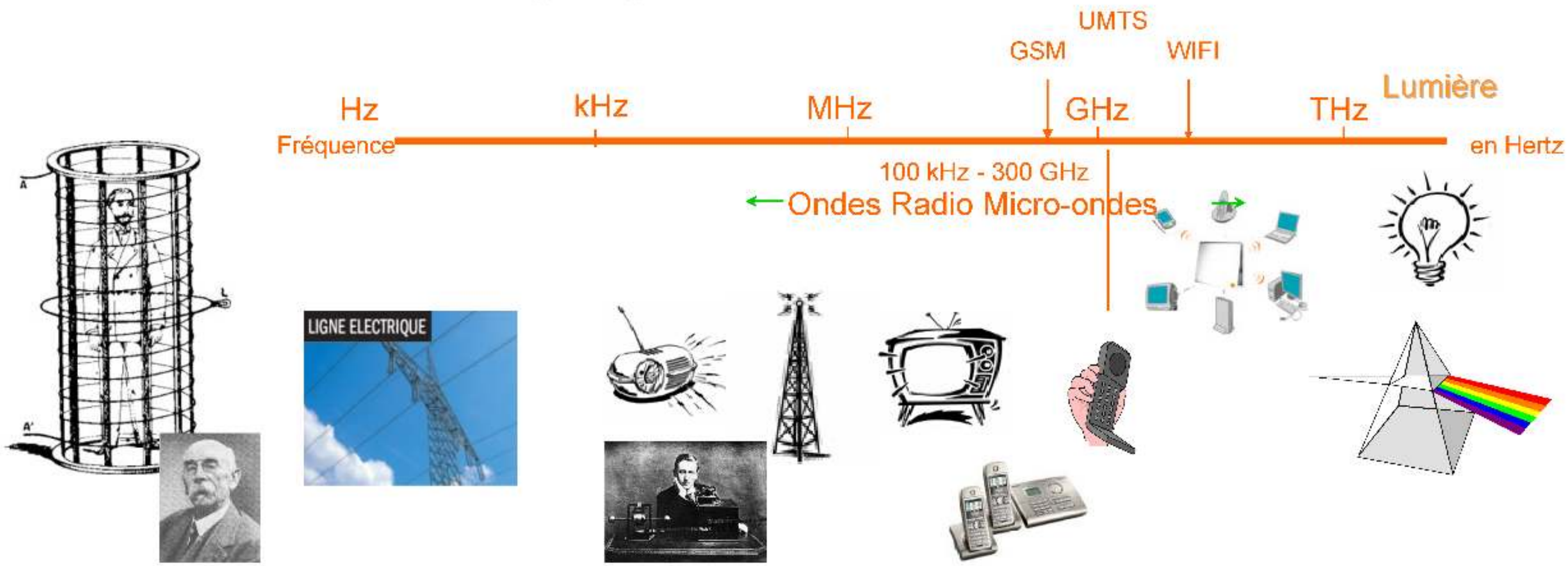
Electric (E) and magnetic fields (H)

In free space

E/H=377Ω



The information is conveyed through the energy of the electromagnetic wave



Risk perception even if there is no evidence of sanitary effect

- Large research effort conducted since 15 years
  - World Health Organisation EMF project
  - Worldwide research effort
  - Several EU and National projects and programs
  - Protection limits exist
  - No evidence of sanitary effect below the legal limits (ICNIRP limits)

ICNIRP limits

Basic restrictions	Public	Workers
Whole body SAR (W/kg)	0.08	0.4
Local SAR (W/kg) Head - Trunk	2	10
Local SAR (W/kg) Limbs	4	20


LA GAZETTE DE BRUXELLES

Actualités Articles Dossiers Liens Réserve

Accueil du site > Articles > Mobilisation contre une antenne relais à Etterbeek

MONDE SANS FIL

Mobilisation contre une antenne relais à Etterbeek

mardi 10 septembre 2013, par La rédaction


Les victimes de l'antenne n'étaient pas au courant

But risk perception

- Euro-barmoter 2010 :
  - 70% say that mobile phone masts have some effects on health.
  - 67 % think that mobile telephones have some effects on their health.

Compliance to limits and Risk Perception

- **Compliance is fundamental but not enough**

today

- **Assess, limit and monitor the exposure is key**

CE CENELEC


N°
ASSEMBLÉE NATIONALE
PROPOSITION DE LOI

Common lab of Orange Labs and Mines Telecom Institute.

Whist Lab
Laboratoire commun de l'Institut Télécom et de Orange Labs

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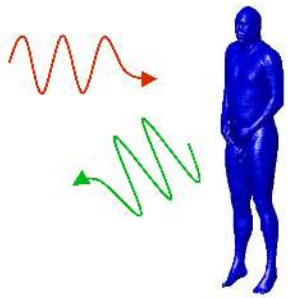
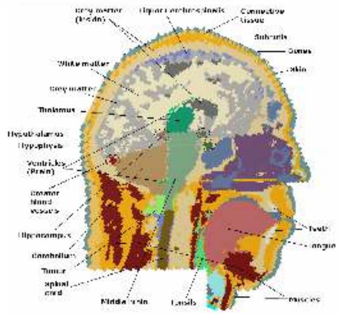
EMF Human Exposure: Absorption

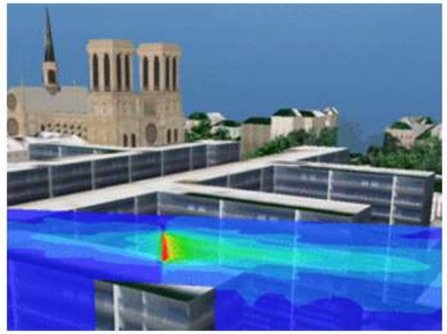
- The absorption depends on
  - Shape
  - Tissues
  - Frequency

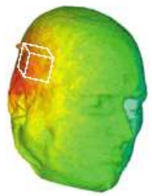


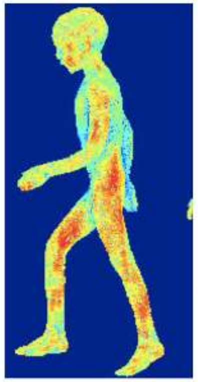


Exposure metrix

- E, H
- …. But also SAR
- The SAR characterizes the power deposited in tissues. It quantifies the absorbed power per mass unit
- The SAR is often averaged over the whole body or over a small mass (eg 1 or 10 g)



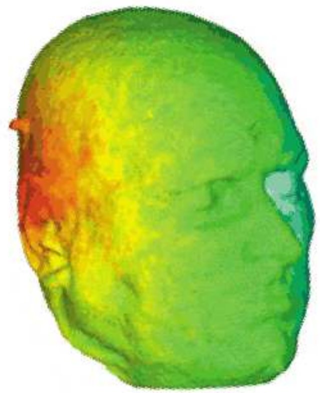




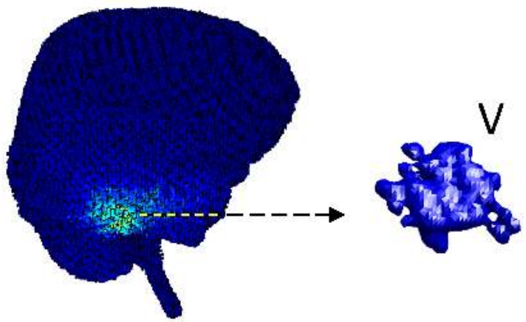
$$SAR = \frac{d\left(\frac{dW}{dm}\right)}{dt}$$

Specific Absorption Rate (SAR)

The SAR is linked to the electric field and to the conductivity



$$\mathbf{P}_{abs\ in V} = \frac{1}{2}\iiint_V \sigma \mathbf{E}^2 dv$$



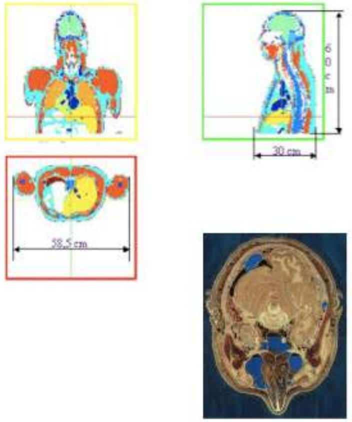
$$SAR = \frac{\sigma E^2}{2\rho}$$

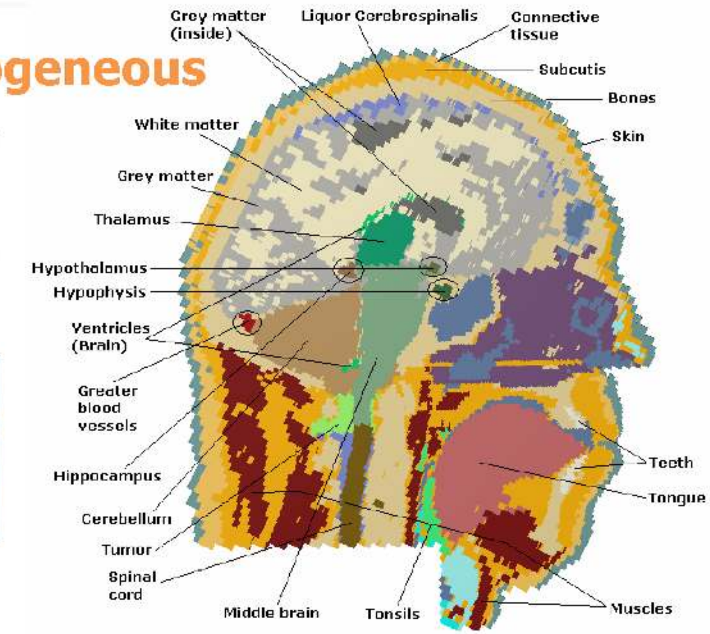
$$SAR_V = \frac{\mathbf{P}_{abs\,\text{in}\,V}}{M_V}$$

Human body : heterogeneous, dispersive and lossy tissues

The field propagation and energy absorption in strongly influenced by heterogeneous tissues

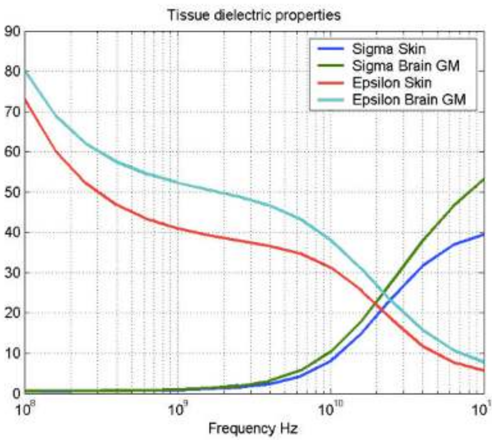
heterogeneous



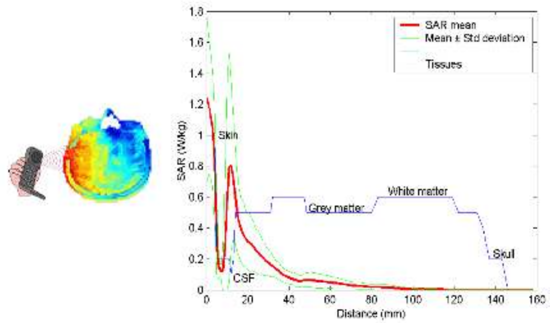


Dispersive and Lossy

F= 900 MHz



Tissue	Epslon	Sigma
Blood	61.3	1.53
Bone_Cortical	12.4	0.14
Bone_Marrow_Infiltrated	11.2	0.22
Bone_Marrow_Not_Infilt	5.5	0.04
Cartilage	42.6	0.78
Cerebro_Spinal_Fluid	68.6	2.41
Eye_Tissue(Sclera)	55.2	1.16
Fat	5.4	0.05
Grey_Matter	52.7	0.94
Muscle	55.0	0.94
Nerve(Spinal_chord)	32.5	0.57
Skin(Dry)	41.4	0.86
Skin(Wet)	46.0	0.84
Tongue	55.2	0.93
White_Matter	38.8	0.59



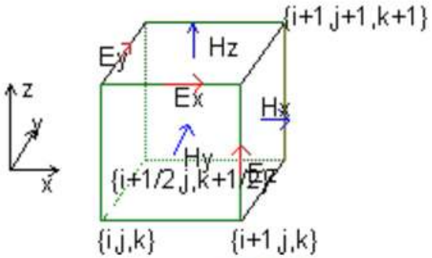
« Deterministic » dosimetry is mature

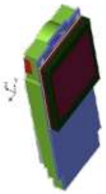
Large effort since 20 years

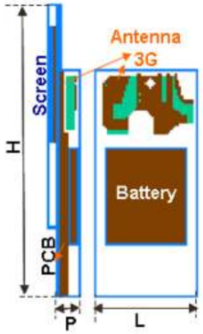
- Experimentally. Probe and protocols have been developped and implemented in standards

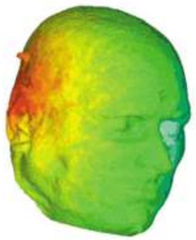
- Numerically: with HPC, GPU, simulations are larger and larger, faster and faster

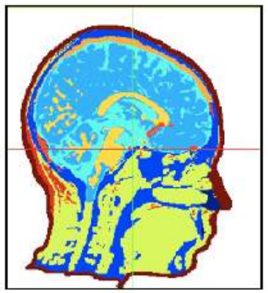
FDTD

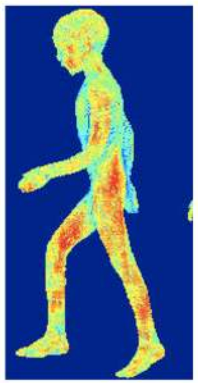






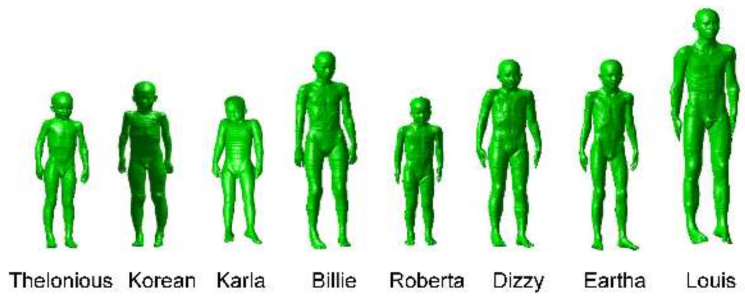






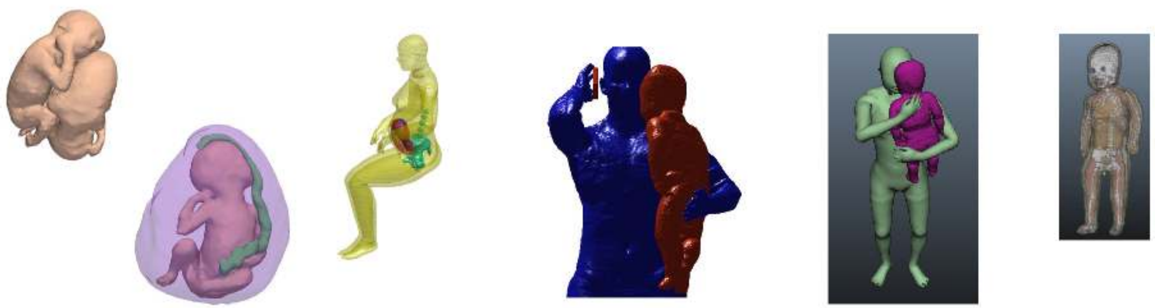
Voxel body models exist

Even if the total number is limited and even if the models have not been randomly selected



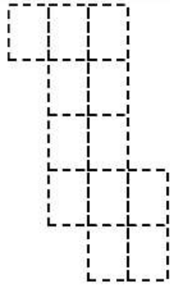
The representativeness of the existing phantom is not guarantee

Develop a new phantom requests months (acquisition, segmentation, validation)



Numerical SAR assessment

In Bio-electromagnetism, the FDTD (Finite Difference in Time Domain) is the most popular method to solve the Maxwell PDE

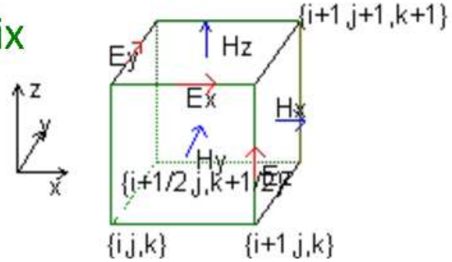


$$rot\vec{E} = -\frac{\partial(\mu_0\vec{\vec{\mu}}_r * \vec{H})}{\partial t}$$

Solve the Maxwell PDE over an orthogonal grid

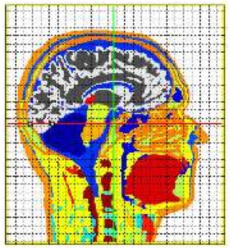
$$rot\vec{H} = \frac{\partial(\varepsilon_0\vec{\vec{\varepsilon}}_r * \vec{E})}{\partial t} + \vec{\vec{\sigma}}\vec{E}$$

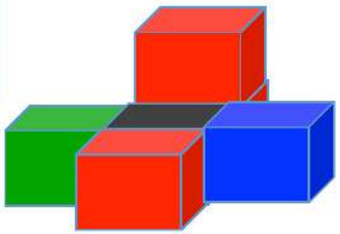
Explicit formulation does not require any matrix innversion



Finite Difference

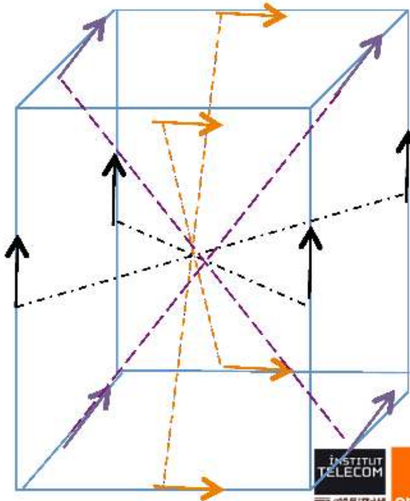
$$\frac{\partial E}{\partial x} = \mu\frac{\partial H}{\partial t} \Rightarrow \frac{E^{n\Delta t}_{i\Delta x} - E^{n\Delta t}_{(i+1)\Delta x}}{\Delta x} = \mu\frac{H^{(n-1/2)\Delta t}_{(i+1/2)\Delta x} - H^{(n+1/2)\Delta t}_{(i+1/2)\Delta x}}{\Delta t}$$





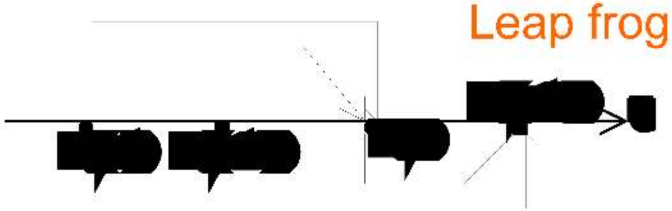
$$P_{abs} = \frac{1}{2}\iiint \sigma E^2 dv$$

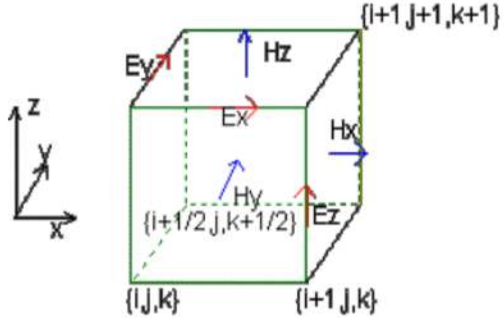
$$SAR = \frac{\sigma E^2}{2\rho}$$

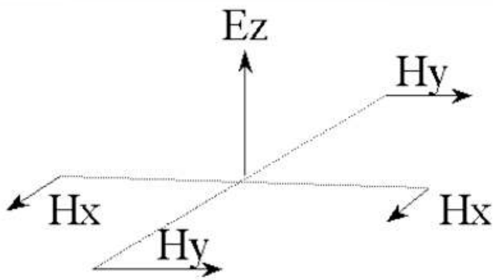


FDTD: Leap frog and Stability

Leap frog





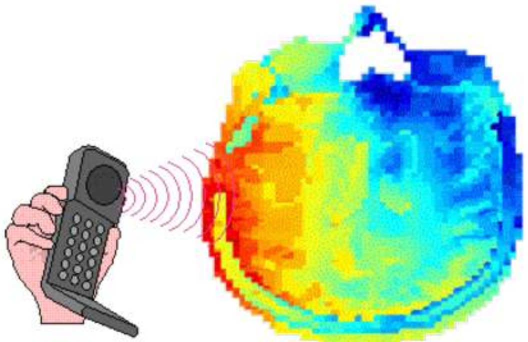


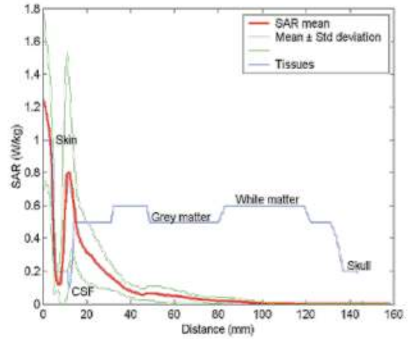
$$E_x^n\left(i-1/2,j,k\right)=E_x^{n-1}\left(i-1/2,j,k\right)+\frac{\Delta t}{\varepsilon_0\varepsilon_r}\cdot\frac{H_z^{n-1/2}\left(i-1/2,j+1/2,k\right)-H_z^{n-1/2}\left(i-1/2,j-1/2,k\right)}{\Delta y}-\frac{\Delta t}{\varepsilon_0\varepsilon_r}\cdot\frac{H_y^{n-1/2}\left(i-1/2,j,k+1/2\right)-H_y^{n-1/2}\left(i-1/2,j,k-1/2\right)}{\Delta z}$$

stability

$$dt \le \frac{1}{v\sqrt{\frac{1}{dx^2}+\frac{1}{dy^2}+\frac{1}{dz^2}}}$$

Divide the resolution by 2
the time computation by 2

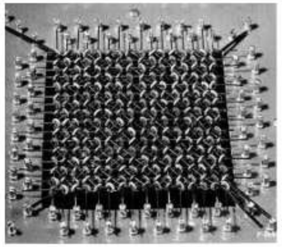




Why FDTD

- Pro
  - Easy to use
  - No matrix inversion
  - Voxel models can be easily used
- Cons
  - Stair case
  - Time computation

Easy but not without constraints

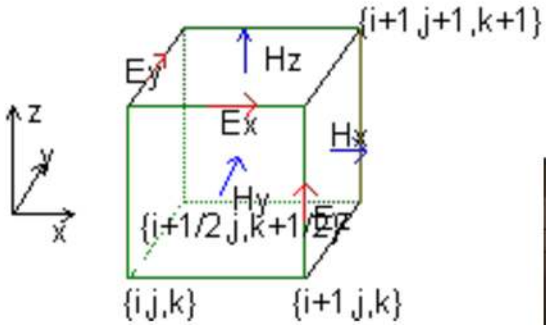


Memory

- 2 mm resolution
  - → 1000x250x250 = 625 10^3 voxels
  - → x 6 field components= 3.75 10^3 data
  - → x 8 bytes= 3 GB
  - → x 4 matrix= 12 GB
  - → + boundary = 15 GB

1 millimeter resolution → 120GB

Divide the resolution by 2 increase the memory by 8 and the time computation by 16



Computation Time

dt ≈ 10^{-12} s, N_step ≈ 1,5 10^4

Speed MPI<40 M cell/s
Speed GPU [40 280] M c/s

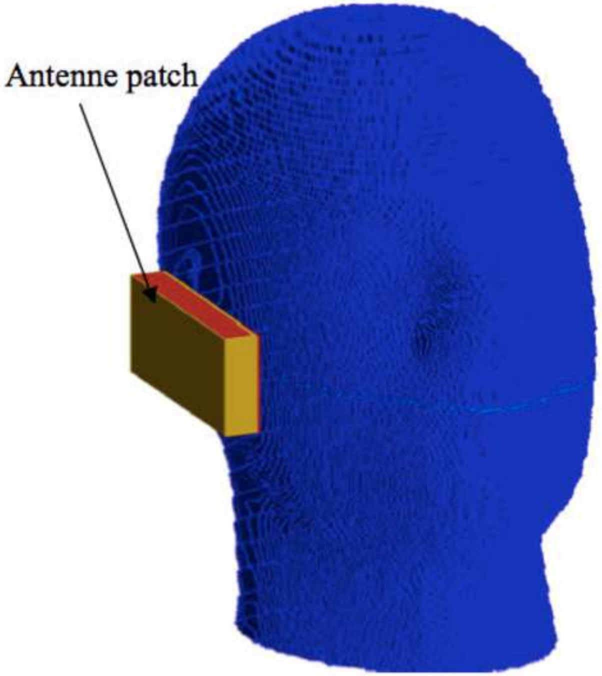
System : 2 CPU intel XEON 12 core 2.4 GHz; 144 Go ; 4 GPU Nvdia Tesla M2090

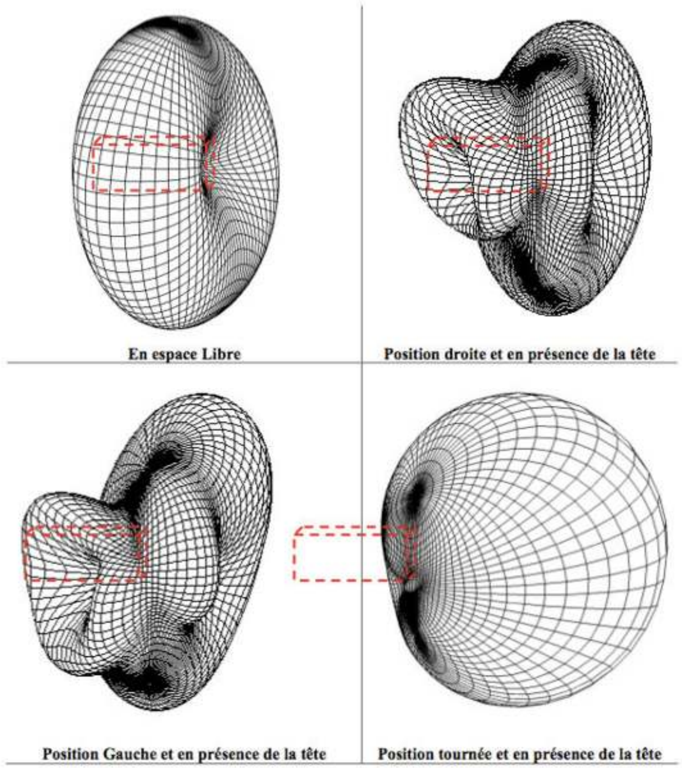
Problem: 440x460x770 Voxels and 17030 time steps

Duration : 2h37 with 280 Mcells/s

orange

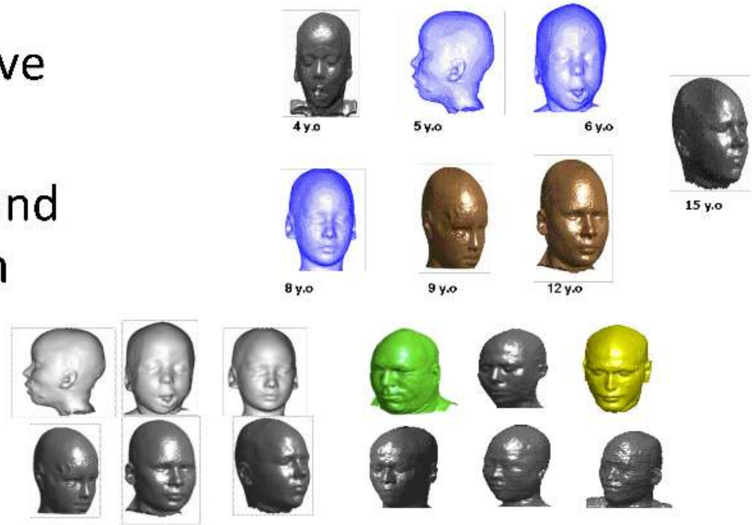
Example of application: Pattern antenna of a mobile close to the head

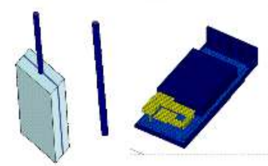


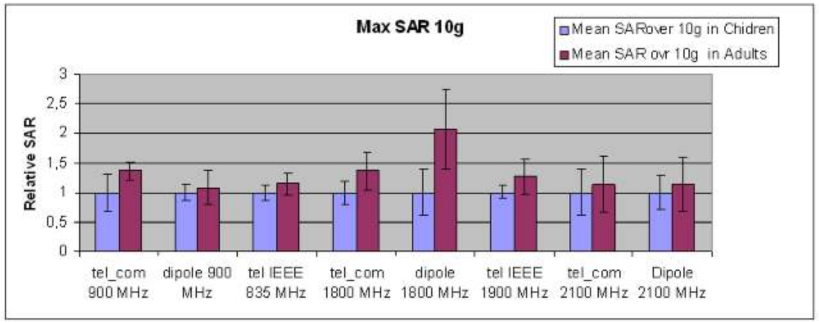


Children vs Adults exposure

- Head models, MRI based, have been developped
- Comparison between adult and child head models have been conducted .





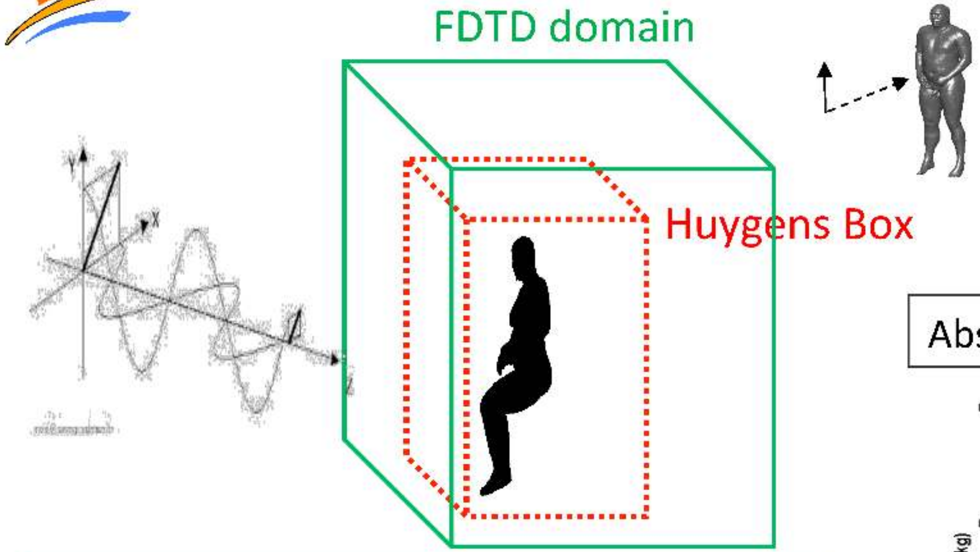


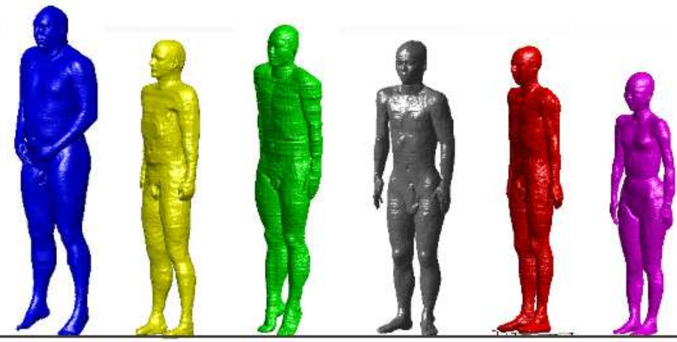
Locally the exposure can differ:
e.g brain peripheral exposure

Analysis of RF exposure in the head tissues of children and adults
J. Wiart, A Hadjem, M F Wong and I Bloch, Phys. Med. Biol. 53 (2008) 3681–3695

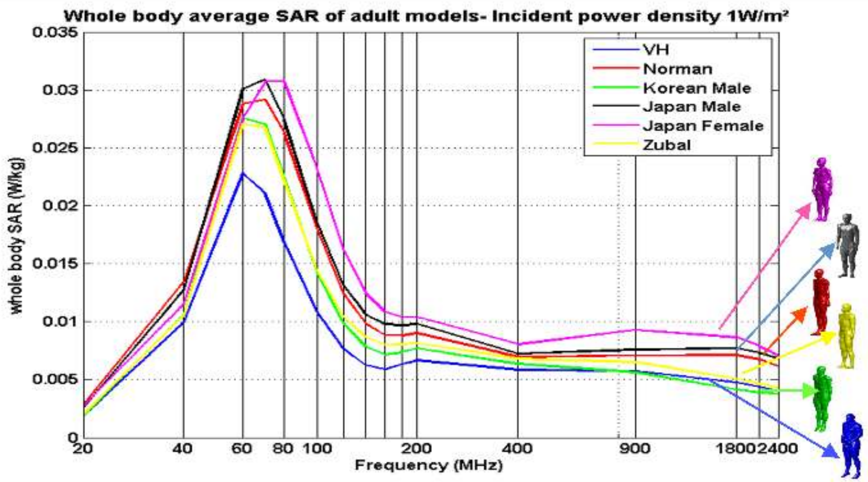
Works perfomed by N Varsier, A Hadjem E Conil and J Wiart

Whole Body exposure from a far source





Absorbed power divided by the weight vs frequency



Huygens Box Principle

- The exposure induced by the incident field can be be performed using the equivalent principle
- With the E.P. only the incident field at the surface is required to assess the field inside the box.
- The far field of base station antenna can be approximated using a plane wave that can used as incident field

A single simulation (1 phantom, 1 fre) = 8 h
16 freq x 6 phantoms → 768 hours… 32 days…

Large influence of the morphology

Works perfomed E Conil,, N Varsier, A Hadjem and J Wiart

Human exposure induced by a "femto cell" at home

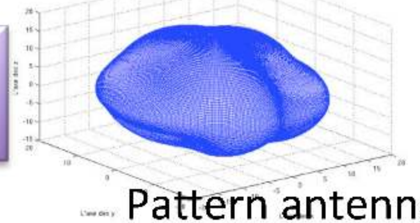
In this case
- crude FDTD simulation unrealizable: too big FDTD domain.
- Plane wave approximation is not valide

The field radiated by a source can be expanded over spherical waves (that are an orthogonal base as the plane waves are)

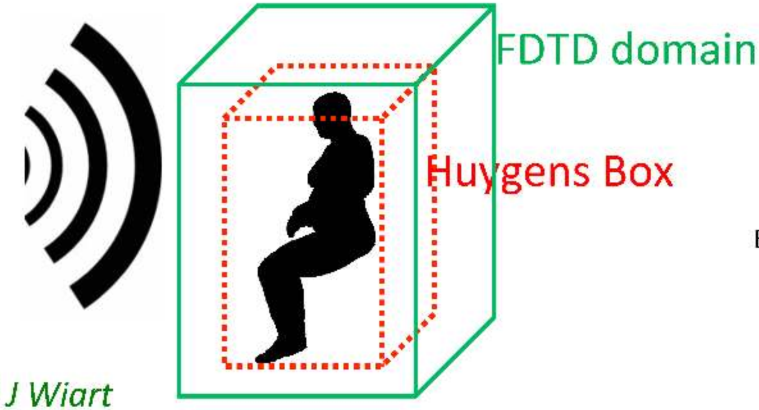
$$\vec{E}(r,\theta,\varphi) = \sum_{k} Q_k \vec{F}_k(r,\theta,\varphi)$$

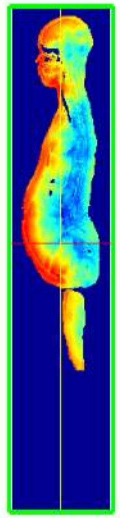
Works perfomed by P. Kersaudy

Measurements can provided the coefficients



Pattern antenna of the « femto »





Exposure induced by the femto

Phd works perfomed by P Kersaudy

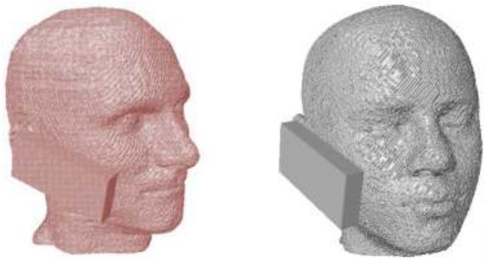
Supervisors O Picon, S Mostarshedi , B Sudret and J Wiart

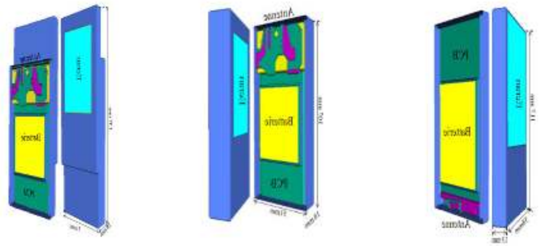
Human exposure induced by a mobile close to the head

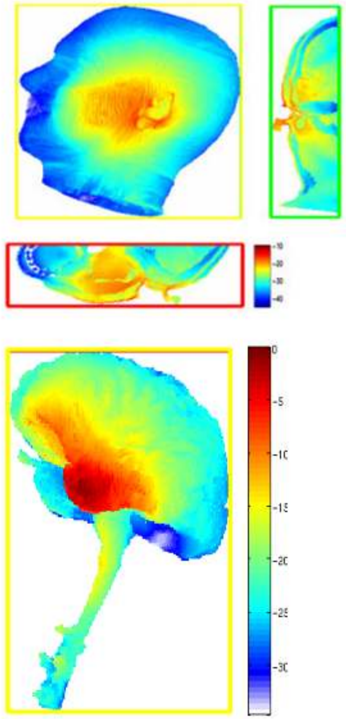
- The source is very close to the tissues. So "Huygens box" cannot be used and must be modelled
- The head models exist.
- The main problem is to locate the phone close to the head

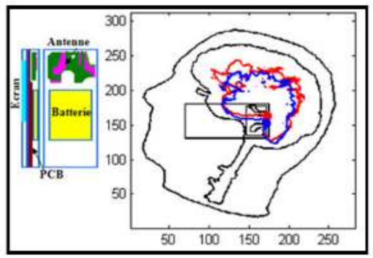
- The accuracy of the simulation depends on the accuracy or the representativeness of the source models

Simulations « head only » request less memory and less time computation (less than 20 minutes)
But preparation time can be relatively important



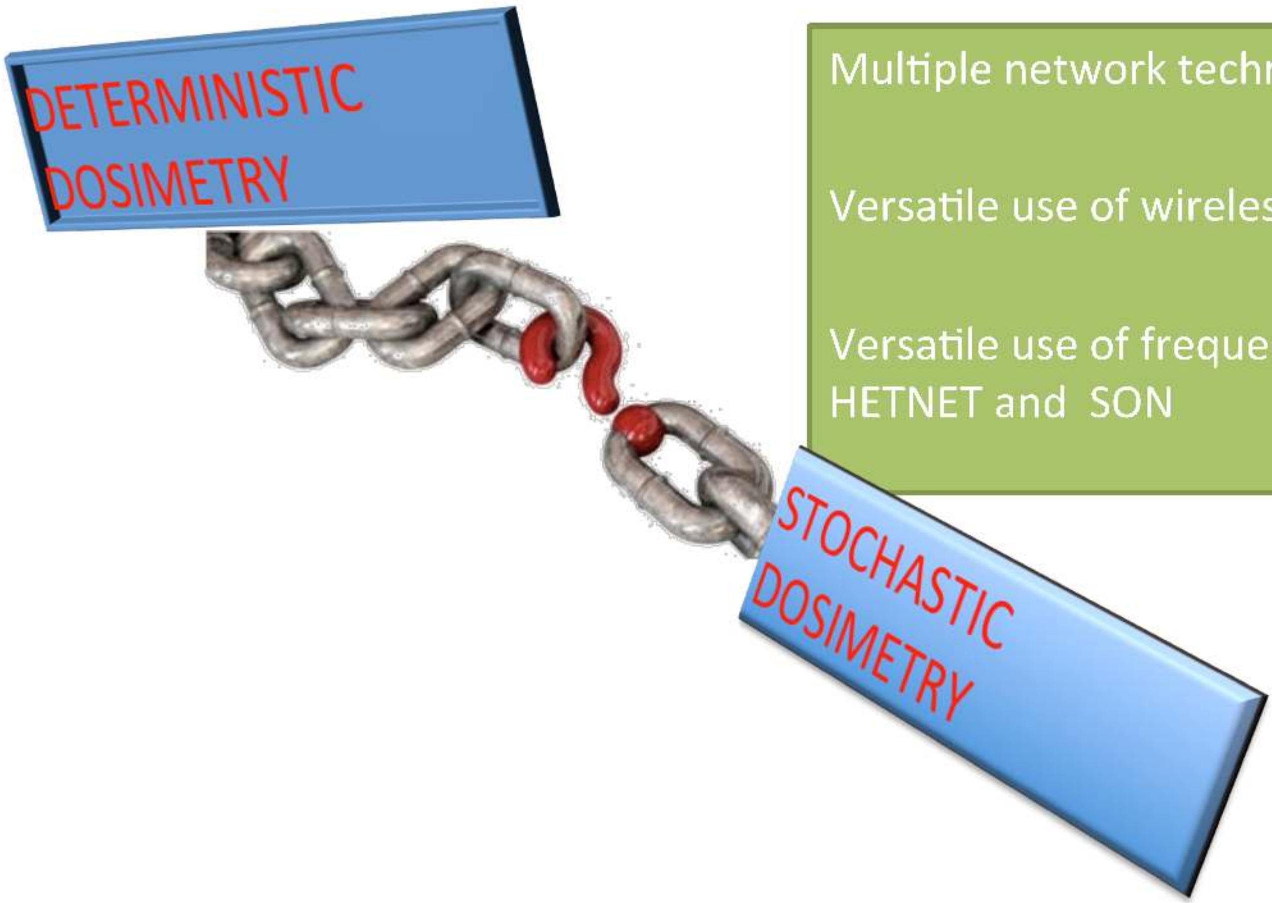






Works perfomed by A.Ghamni, N Varsier, A Hadjem E Conil and J Wiart

Today exposure is facing variability



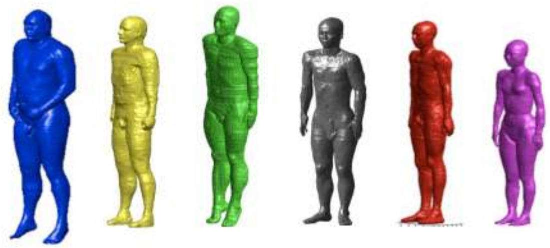
Multiple network technologies

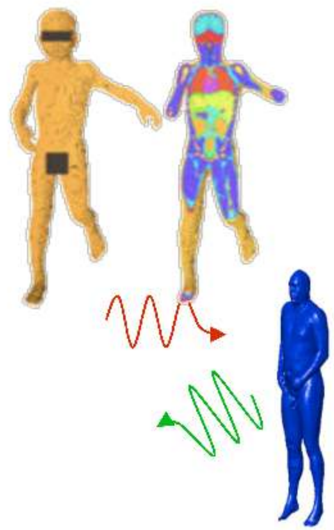
Versatile use of wireless communication

Versatile use of frequencies with HETNET and SON

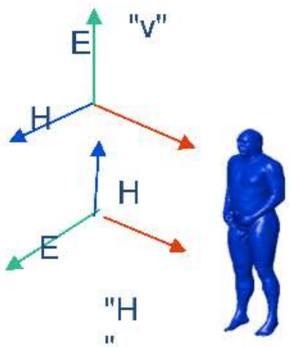
Morphology, Sources, Posture… have large influence.

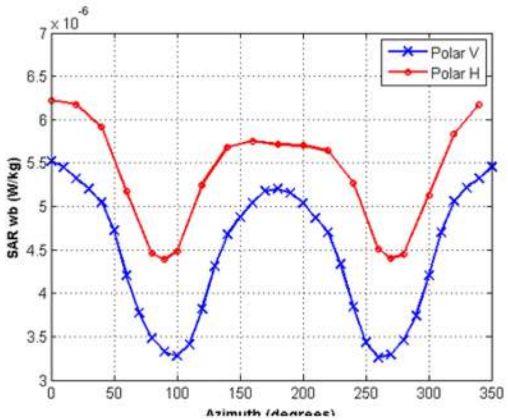
Total absorbed power divided by the weight



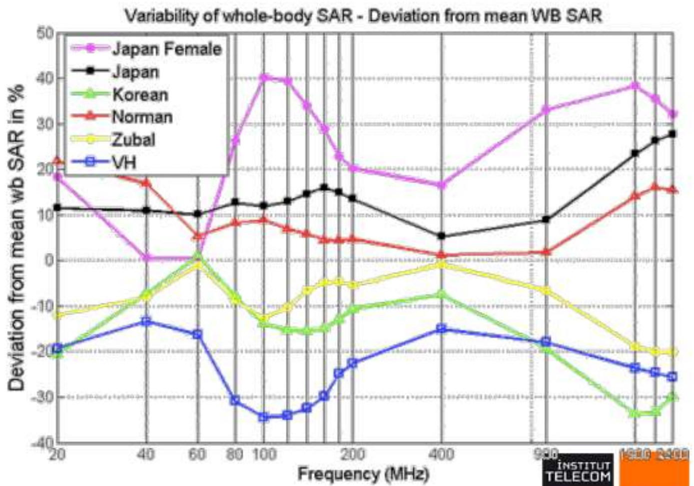


Large Variability



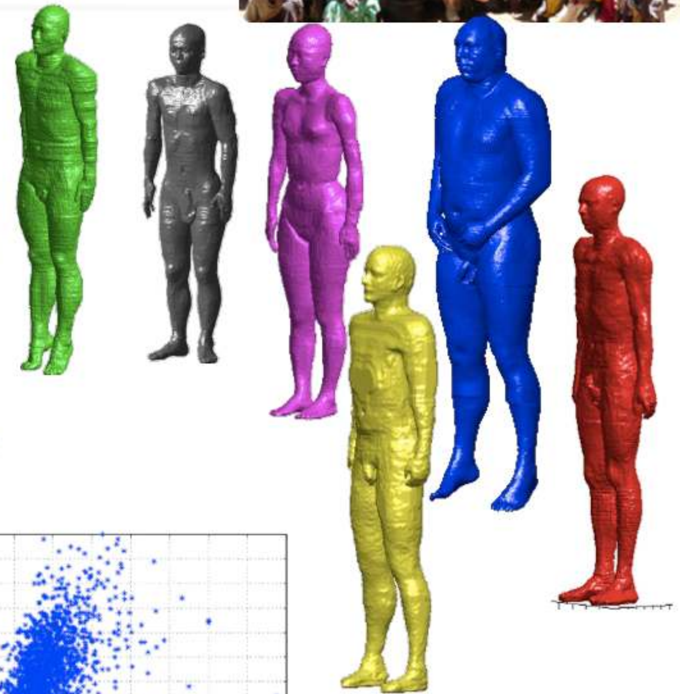


2.1 GHz

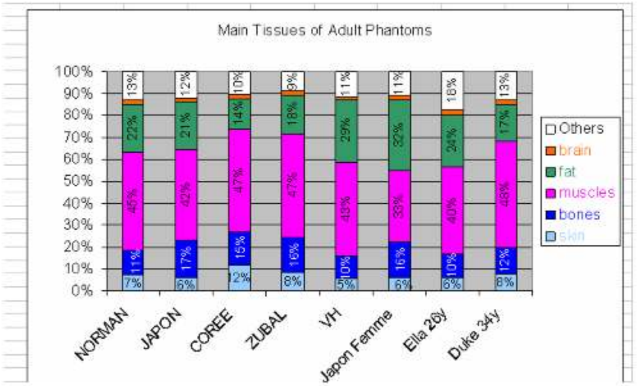


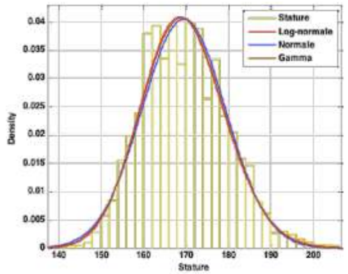
Variable Morphology

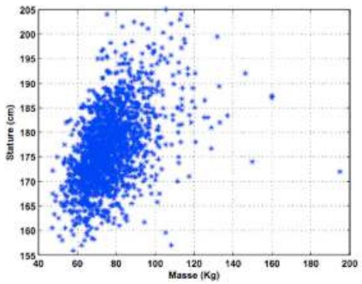
The first challenge has been to get information

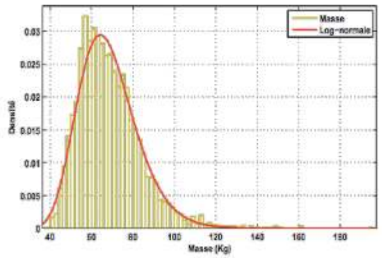


Variation within the same age

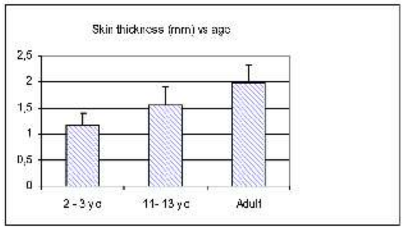


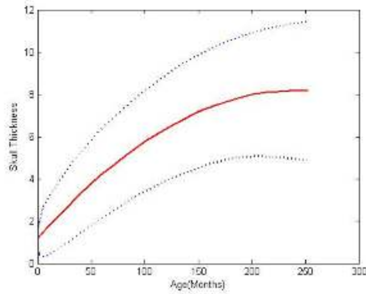






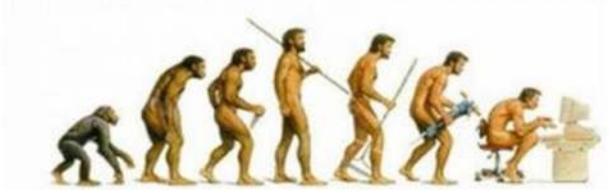
Variation with age





Evolving technologies and versatile use

Source location and user posture

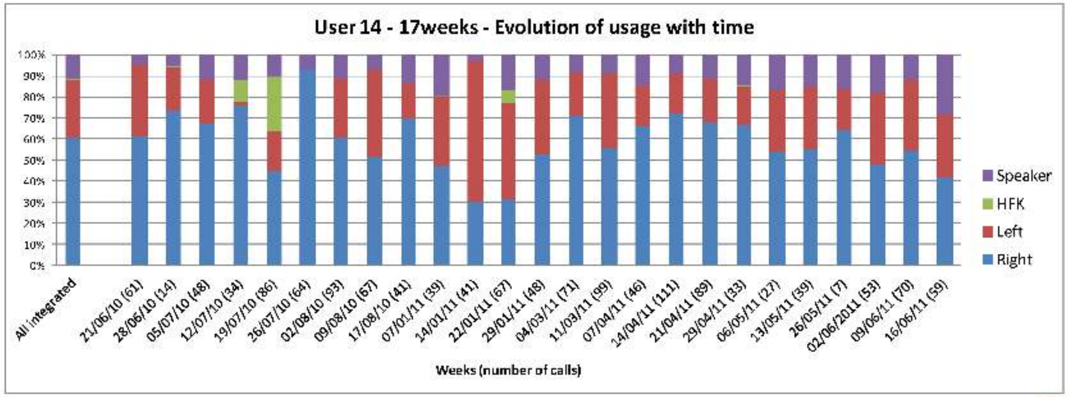


Size and antenna location

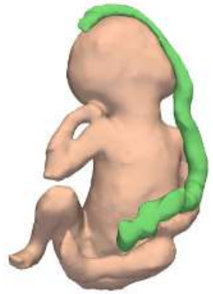
Variation of the laterality use

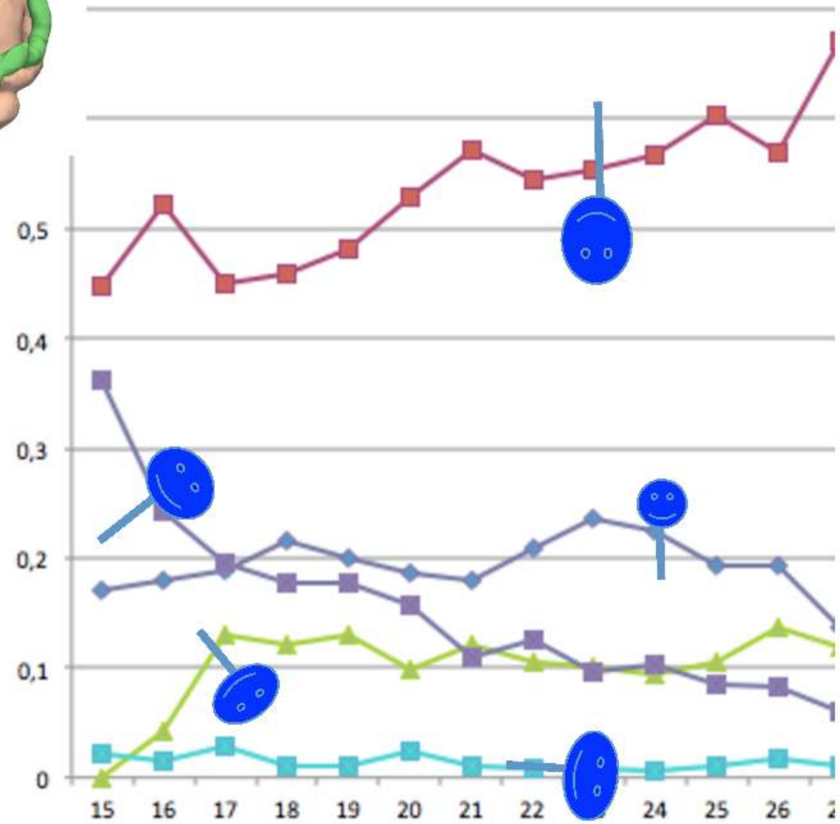
XmobiSense

Important for epi studies.



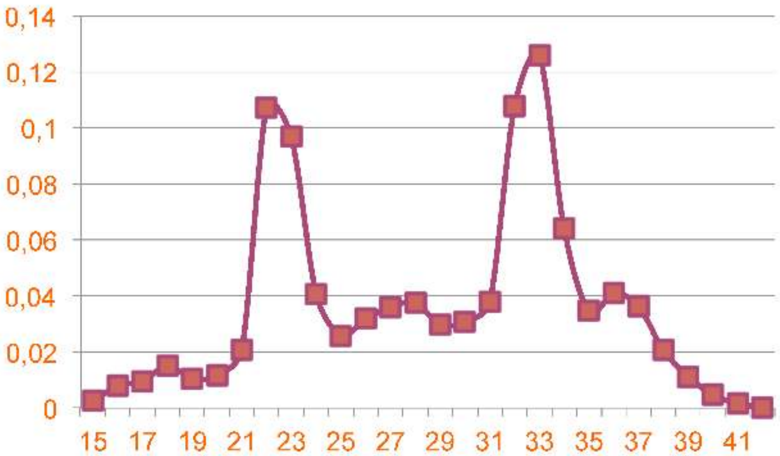
Variable Posture: e.g Fetus posture





Posture occurrence vs weeks of pregnancy

Observation vs weeks



More than 15000 observations performed at Maternité Port Royal under the responsability of Docteur Gilles Grangé

Dielectric properties uncertainties

- Most of the Dielectric properties measurement have been performed with mamalian animals

- The dielectric properties are tissues and frequency dependent

Standard deviation of the conductivity of the skin of dry face can be 10%

- The dielectric properties of tissues are age dependent
  - A Peyman et al pmb 2009,

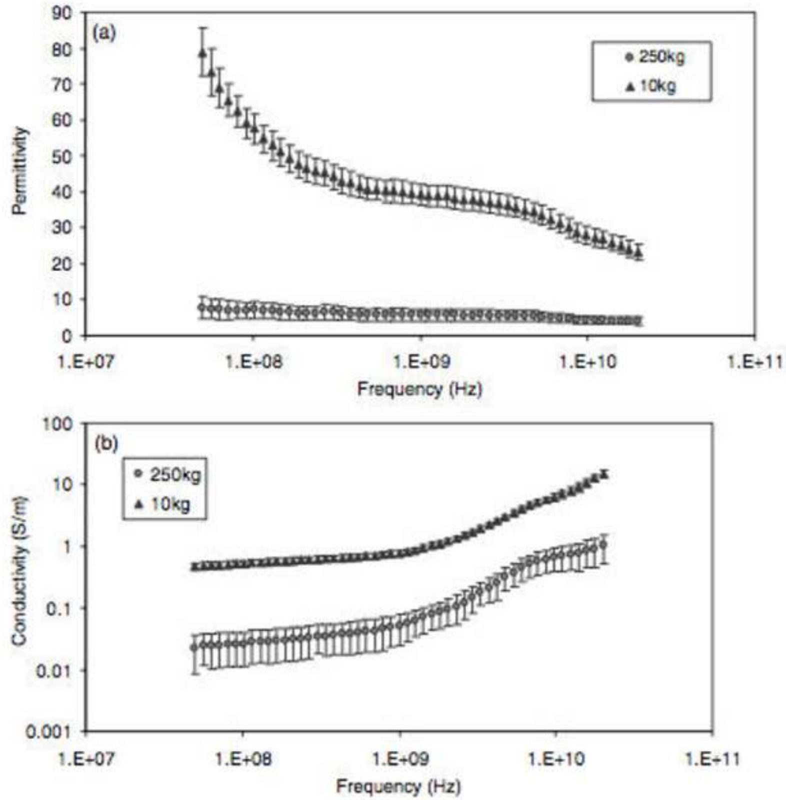
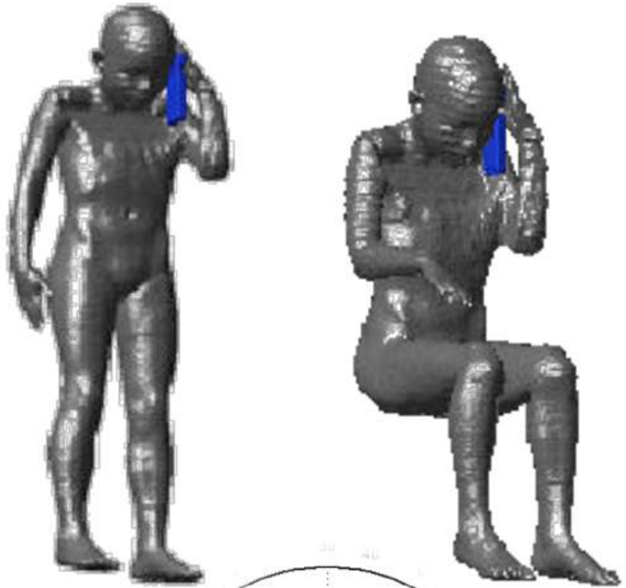


Figure 4. The measured (a) permittivity and (b) conductivity of bone marrow 30% for 10 and 250 kg pigs. The error bars are the total combined uncertainty with $k = 3$ which represent the 99% confidence interval.

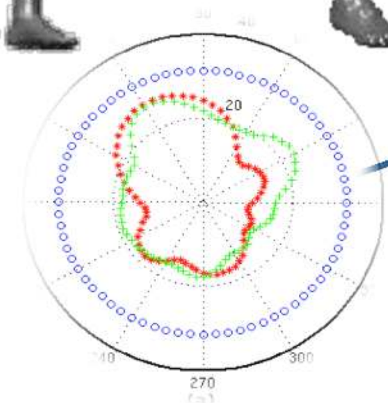
Variable SAR induced by the variable gain of the couple mobile+user

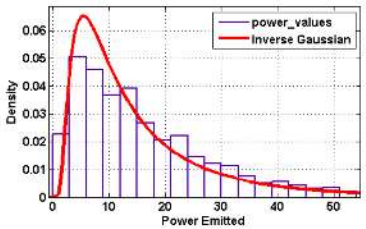


- The pattern antenna (gain) of « mobile +user » depends on the posture and location of the phone
- The human exposure (SAR) depends on the power radiated by the phone

$$P_e * G_e * \underbrace{PL * G_r}_{constant} = \underbrace{P_r}_{fixed}$$

$$P_e * G_e(\theta_{LOS}, \phi_{LOS}) = 1$$





Considering PE x GE known, what is the variation of SAR. In this case is the relative position of the phone is fixed so SAR depend only the power emitted:

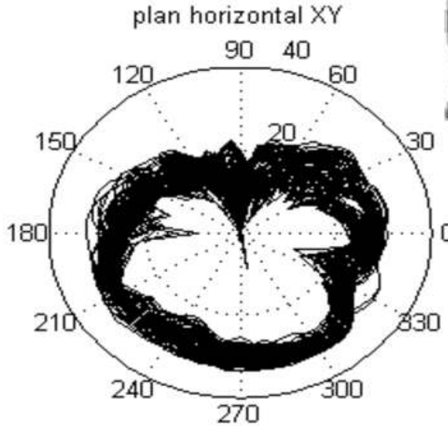
$$P_e = \frac{1}{G_e(\theta_{LOS}, \phi_{LOS})}$$

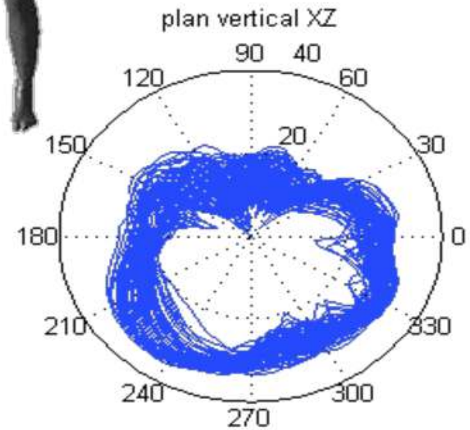
Phd works perfomed by A Krayni

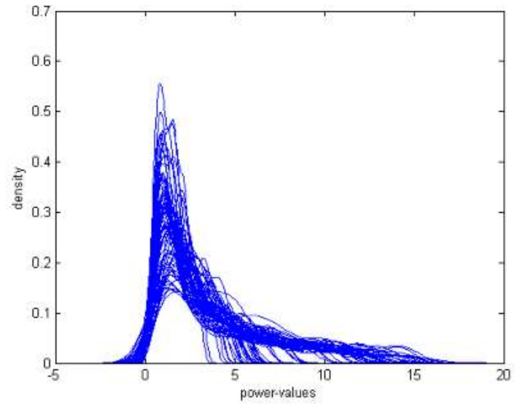
Supervisors A Sibille, A Hadjem and J Wiart

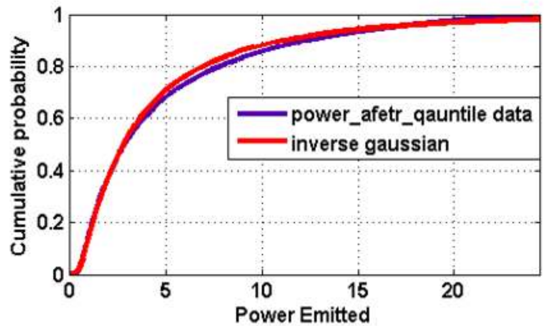
Variation of the power emitted by a Tablet

3 variables. Y,Z,Teta
LHS Planning experiment
80 simulations

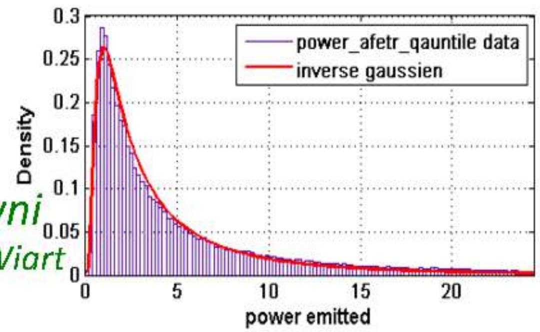






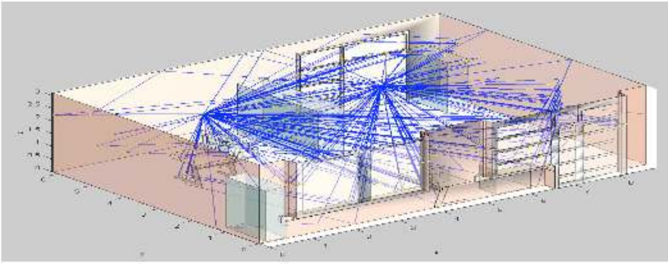


Phd Works perfomed
by A. Krayni



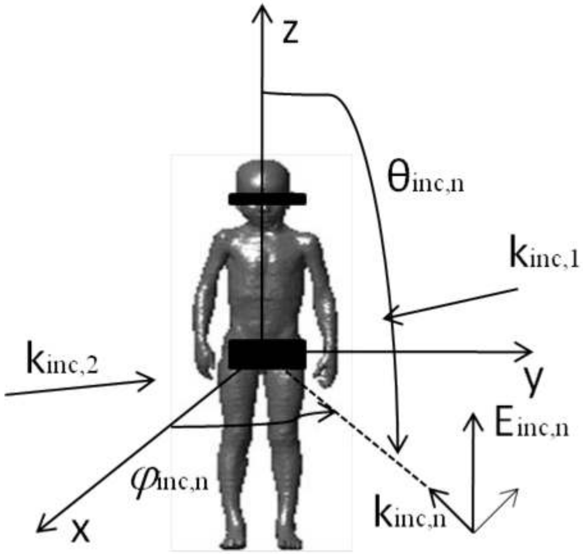
Phd works perfomed by A Krayni
Supervisors A Sibille, A Hadjem and J Wiart

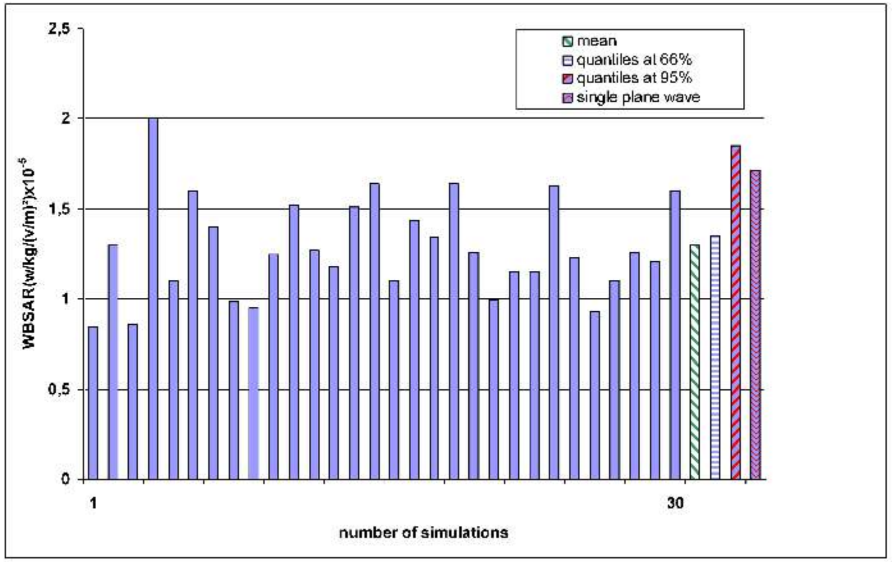
Variable exposure induced by multiple reflexions



5 incident waves

- Uniform incident angles
- Log normal amplitudes
- Uniform phase





Phd works perfomed by Th Kientega

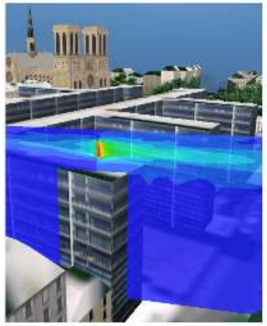
Supervisors O Picon and J Wiart

EMF exposure and Geostatistical tools

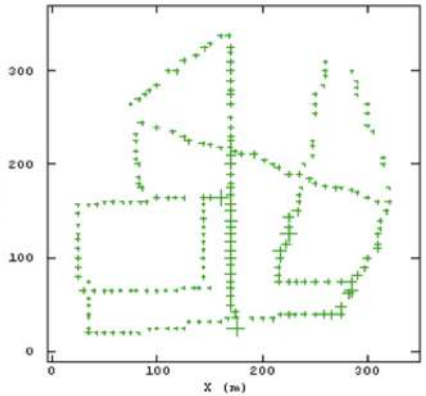
Public questions request exposure assessment

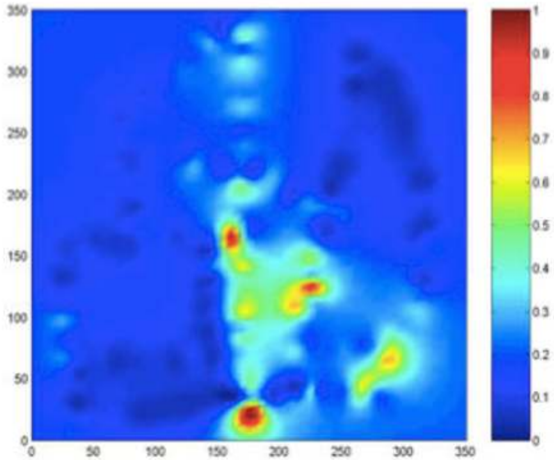
Simulation are facing limitations (e.g. dielectric properties, geometrical characteristic of the buildings, simulation time…)

Measurement are also facing limitations (e.g uncertainty of the assessment, fading, number of measurements..)



Ordinary Kriging applied



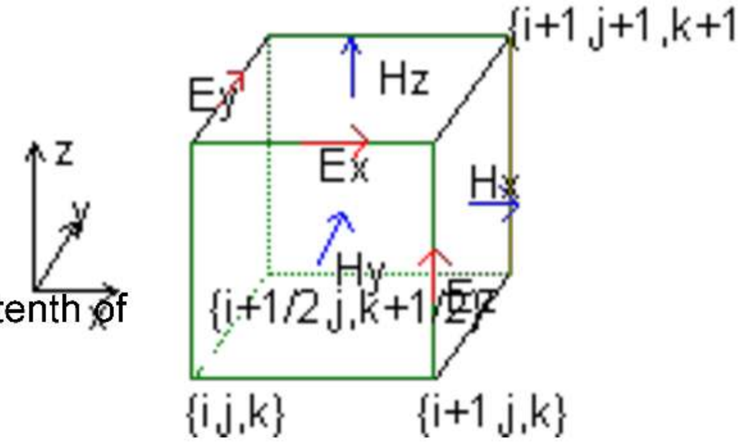


Phd works perfomed by Y Ould Isselmou

Supervisors : H Vandernackel, W tabbara and J Wiart

Variability management: the constraints

- FDTD calculations
  - Whole body : few hours
  - Head only : few tenth of minutes

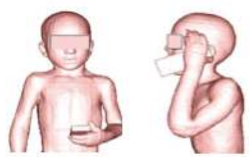


- Simulation preparation
  - Model deformation and source positioning : from tenth of minutes to few hours

- Human model
  - Limited number.
  - Model Development : from few month to few years

- Source models
  - Model Development :few weeks to few months

Surrogate model are needed

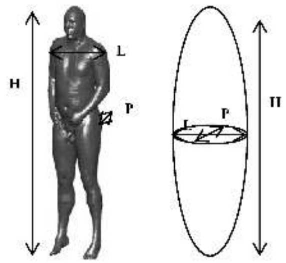


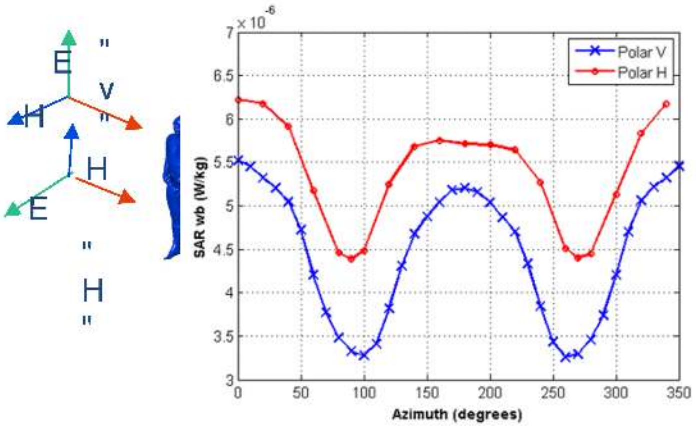
Simplistic Approach of the whole body exposure

- In the RF domain there is no resonnance, then the whole body SAR is is proportional to the surface cross section

- Human body can be approximated using Ellipsoid

$$surface = \pi \frac{H}{2}\sqrt{\frac{L^2}{2}\cos(\theta)^2 + \frac{P^2}{2}\sin(\theta)^2}$$





Based on simulations performed vith VH

$$P(W) = 0.72 * S(m^2) * DSP\left(\frac{W}{m^2}\right) \pm 5\%$$

Representativeness?

Works perfomed by E Conil , A Hadjem MF Wong and J Wiart

Specificity of Dosimetric Problem.

++ SAR is a regular function

- - simulation cost does not allow large number of sampling

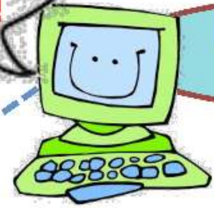
large number of input

small number of human model

simulation preparation can be heavy

Simulations are very heavy and long to carry

Challenges of the stochastic dosimetry



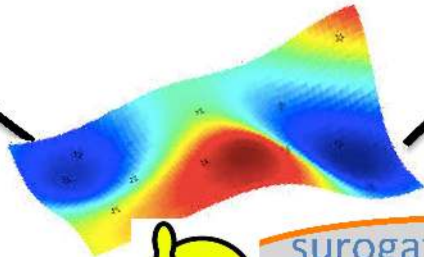
FDTD calculations
high cost

Vector of input variables

$x \in \Re^M$

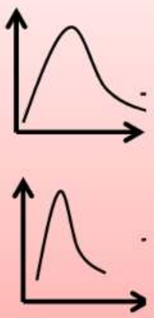
Vector of output variables

$y = \mathcal{M}(x)$



surrogate model M
low cost

- User variables
  - morphology
  - posture
- Usage variables
  - devices
  - type of service
- Network variables
  - load
  - type of cells
  - RAT
- …



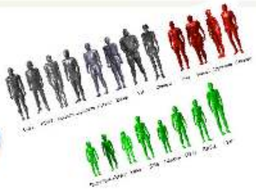
Challenge: Characterise the input

- Surrogate model
  - analytical model
  - **polynomial chaos**
  - **gaussian process**
  - krieging
  - …

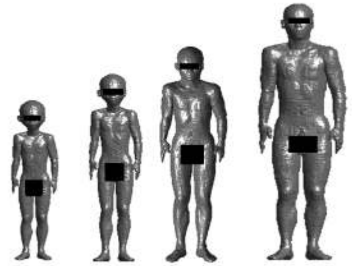
- Global variable whole body SAR
- Local variables
  - 10g SAR
  - brain SAR
  - …
- …

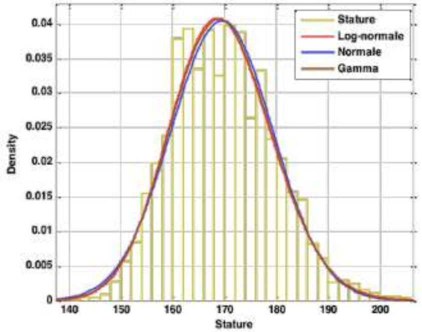
Challenge: surrogate model with the minimum cost

Morphology and exposure how to deal with?



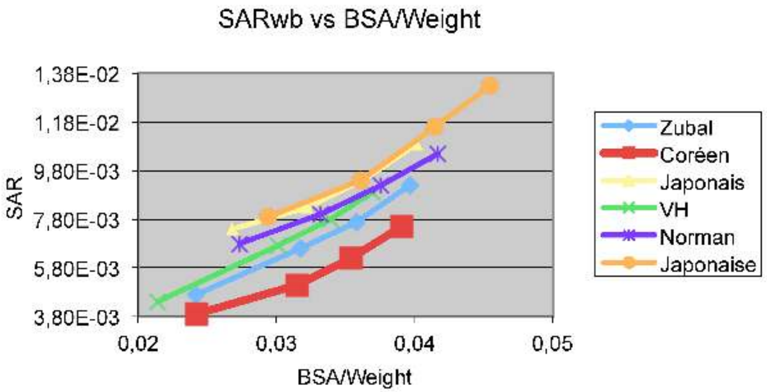
Morphing can be performed based on external data

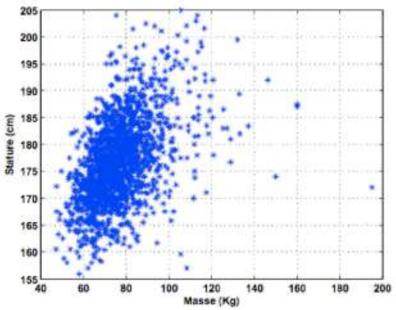


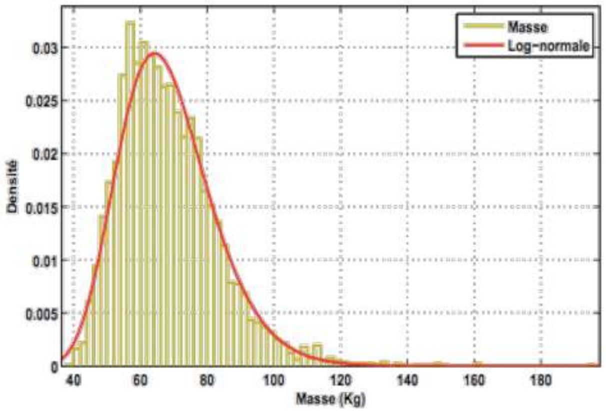


3D models are missing

Some data are known by







Whole Body SAR vs morphology first approach

$$y_{WBSAR,1} = \alpha x_{bsa} + \varepsilon_1$$

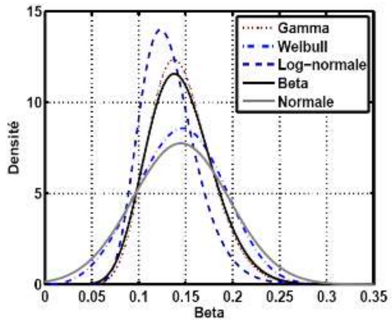
$$y_{WBSAR,2} = \beta x_{bmi} + \varepsilon_2$$

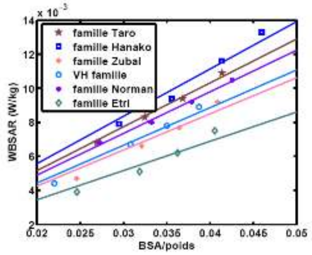
$$y_{WBSAR,3} = \gamma x_{poids} + \varepsilon_3$$

- $Y_{WBSAR,i}$: Whole body SAR WBSAR
- x_{bsa} : Body Surface Area/Weight
- x_{bmi} : $(BMI)^{-1}$
- x_{poids} : $(Weight)^{-1/3}$
- ε_1, ε_2, ε_3 : models errors

Mean square regression Based on 12 body models

Model	Param. estimé	p-valeur t-test	I.C à 95%	R^2
BSA/weight	0.25	10^{-11}	[0.21,0.28]	0.78
BMI^{-1}	**0.15**	**10^{-11}**	**[0.14,0.16]**	**0.87**
$weight^{-1/3}$	0.027	10^{-6}	[0.0235,0.03]	0.67





WBSAR model : $Y=\beta.X$
Where $X = BMI^{-1}$

Using morphing

Facts: β is positive, there is an upper limit

Additional hypothesis:

- The existing phantom have been built to represent mean population

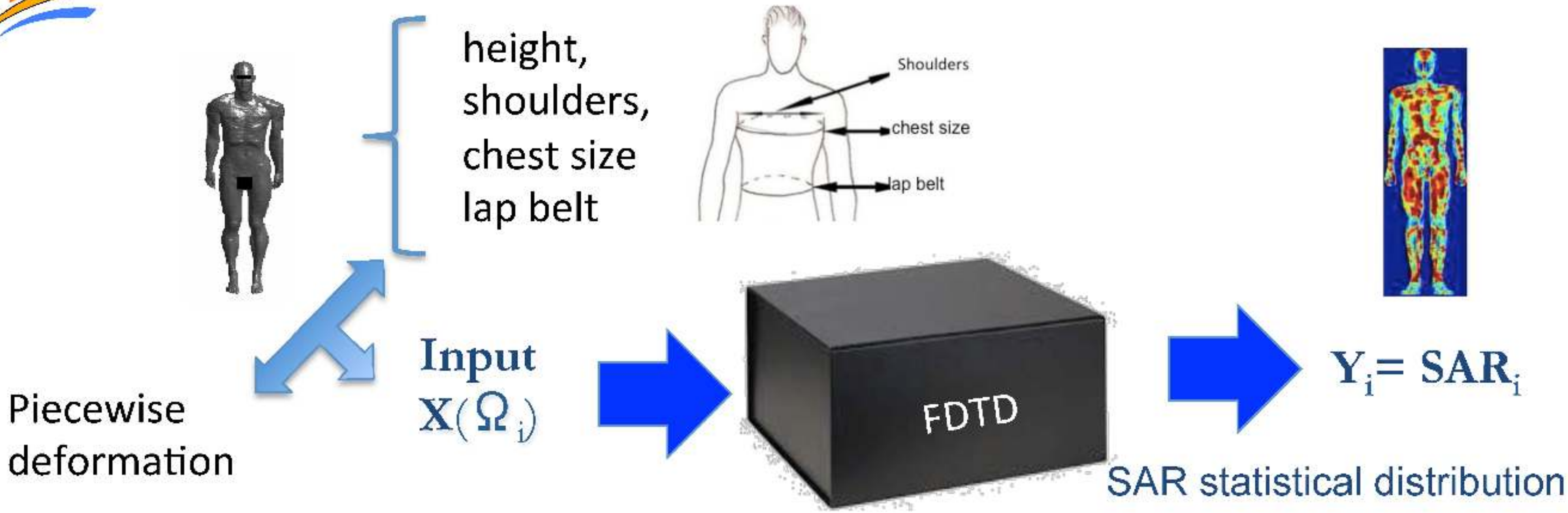
$<\beta> = 0.15$

- β min =0
- symetry of β β max =0.3

law	95% quantile WBSAR (mW/Kg)
Gamma	10
Beta	9.8
Normal	11
Weibull	10.5
Log-normal	9.9

Phd works perfomed by A El Habachi
Supervisors E Vasquez, G Fleury and J Wiart

Second approach using Polynomial Chaos



$$Y = M(X)$$ With $$E(Y^2) < \infty$$

$$Y = \sum_k \beta_k \Psi_k(X)$$

Where β_k are the coefficients of the polynomial chaos expansion

Ψ_k are the basis of of the polynomial chaos.

Projection and Quadrature approach to get the coef

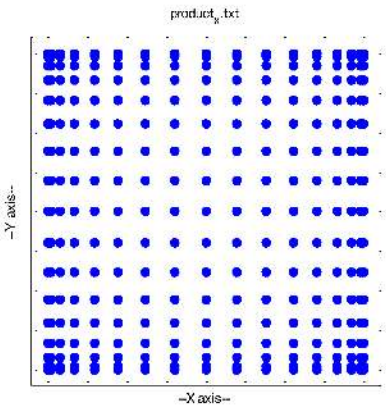
Ψ_k are orthogonal

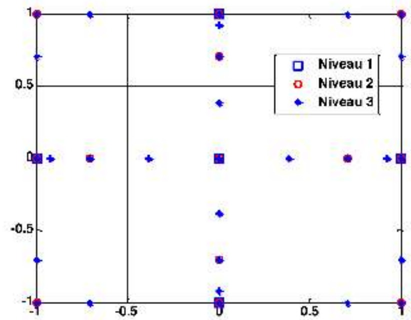
$$\beta_k = \int Y(x)\Psi_k(x) f_X(x) dx$$

Modal description is often used in electromagnetism and therefore the projection can be considered as "natural" in dosimetry.

$$\beta_k = \frac{1}{\left\|\Psi_k\right\|^2} \int SAR(x).\Psi_k\left(x\right) pdf_X(x) dx.$$

In fact even with quadrature, the projection approach leads to have large number of FDTD simulations.





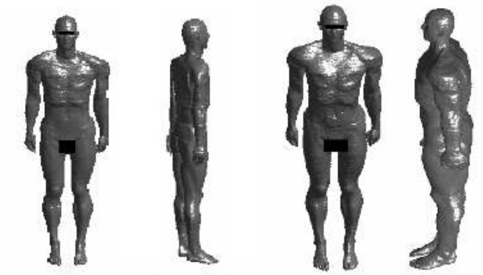
	3 D	4 D
Ordre 1	7	9
Ordre 2	25	41
Ordre 3	69	137
Ordre 4	177	401
Ordre 5	441	1105

Variability on the Propagation of a Plane Wave Using Stochastic Collocation Methods in a Bio Electromagnetic Application
Silly-Carette et al   IEEE MWCL 2009

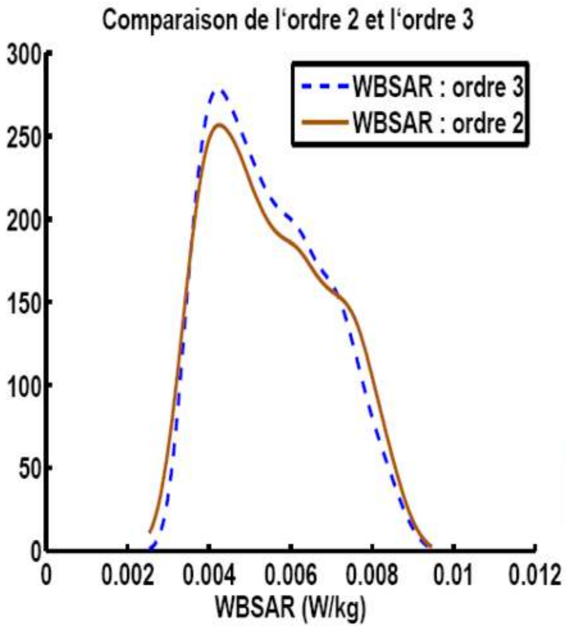
Phd works perfomed by J Silly Carette
Supervisors V fouad Hanna, D Lautru MF Wong and J Wiart

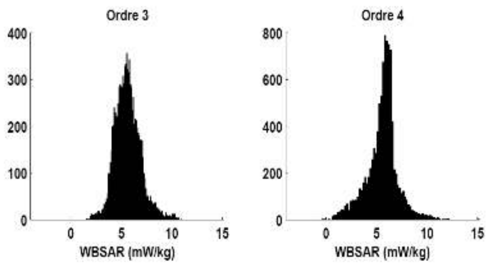
WBSAR vs morphology using Polynomial Chaos and projection

- Sparse Quadrature : « Clenshaw Curtis »
- Smolyak tensorisation
- 4 input parameters: height, shoulders, chest size, lap belt
- Morphed human models



Simulations cost
~ 17 days with GPU, 4 months CPU





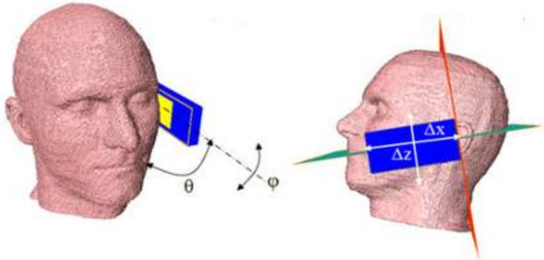
	3 D	4 D
Ordre 1	7	9
Ordre 2	25	41
Ordre 3	69	137
Ordre 4	177	**401**
Ordre 5	441	1105

Mean = 5.3 mW/kg
95% quantile WBSAR = **7.9 mW/kg**

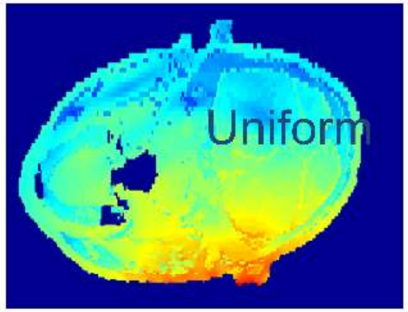
The projection approach is not suitable for dosimetric problems

Phd works perfomed by A El Habachi
Supervisors E Vasquez, G Fleury and J Wiart

Influence of the phone position closed to the head using Polynomial Chaos



SAR$_i$



Ω_i → Input $X(\Omega_i)$ →

→ $Y_i = SAR_i$

SAR statistical distribution

	θ	Φ	Δx	Δz
	[0 -30°]	[-15°+15°]	[5 - 30 mm]	[-10 +10mm]

- same head
- same phone
- different phone position

Coefficients assessment using Regression

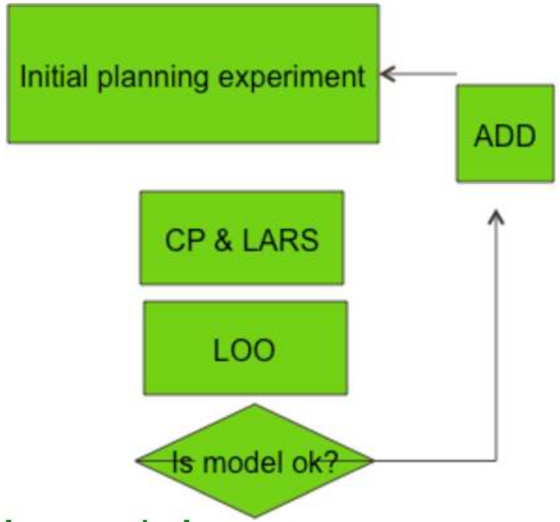
Since the projection approach is not suitable for dosimetric problems we used regression

$$\hat{Y} = \sum_{k=1}^{N} \beta_k \Psi_k(X)$$

Considering a truncature Regression can be used to get the coefficients.

$$\hat{y} = \begin{pmatrix} \hat{y}_0 \\ \hat{y}_1 \\ \vdots \\ \hat{y}_P \end{pmatrix} \qquad Z = \begin{pmatrix} \Psi_0(\xi^{(1)}) & \Psi_1(\xi^{(1)}) & \dots & \Psi_P(\xi^{(1)}) \\ \Psi_0(\xi^{(2)}) & \Psi_1(\xi^{(2)}) & \dots & \Psi_P(\xi^{(2)}) \\ \vdots & \vdots & \ddots & \vdots \\ \Psi_0(\xi^{(n)}) & \Psi_1(\xi^{(n)}) & \dots & \Psi_P(\xi^{(n)}) \end{pmatrix}$$

$$\hat{\beta} = (Z^T Z)^{-1} Z^T y$$



Leave one out to analyse the global accuracy of such model

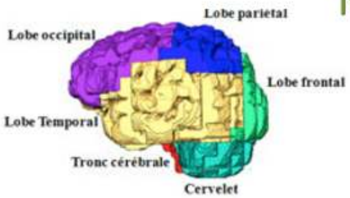
If the model is not as expected then a new experiment has be added

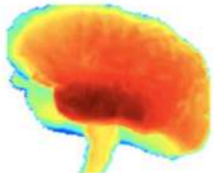
Influence of the phone position closed to the head

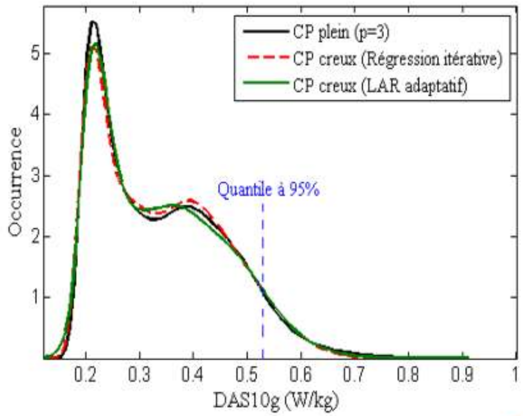
Latin hyper sampling

PC + LOO → 122 FDTD simulations

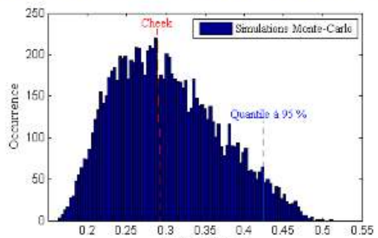
Maximum SAR over 10g in the head







Maximum SAR over 1g in the brain

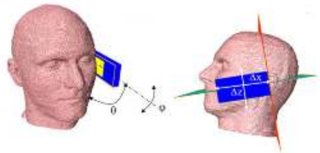


Phd works perfomed by A Ghanmi

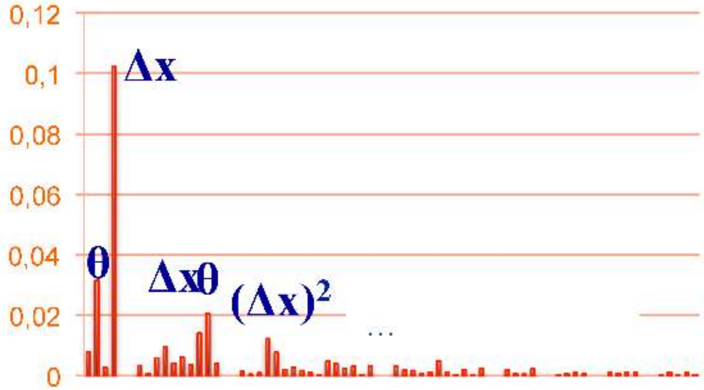
Supervisors O Picon and J Wiart

Uniform

	θ	Φ	Δx	Δz
	[0 -30°]	[-15°+15°]	[5 - 30 mm]	[-10 +10mm]



Sensitivity analysis

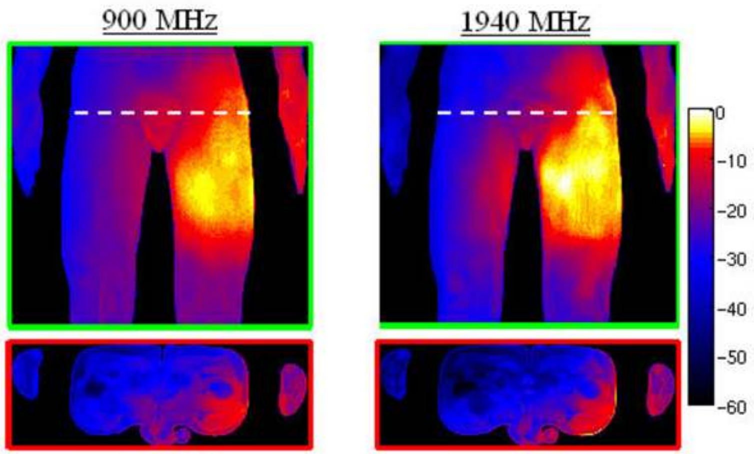


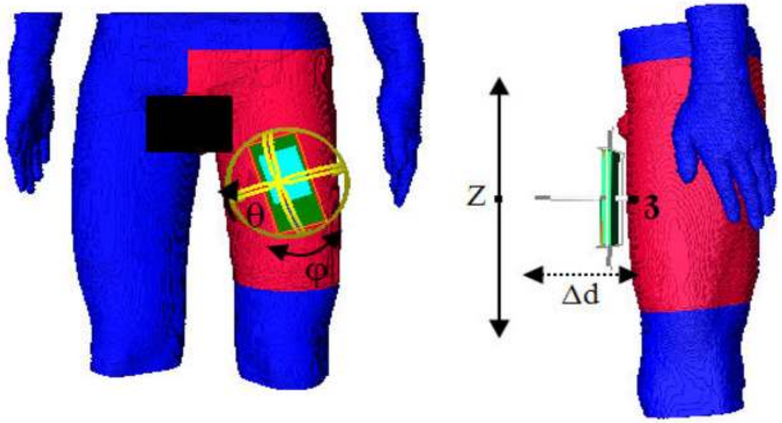
Genital organs exposure

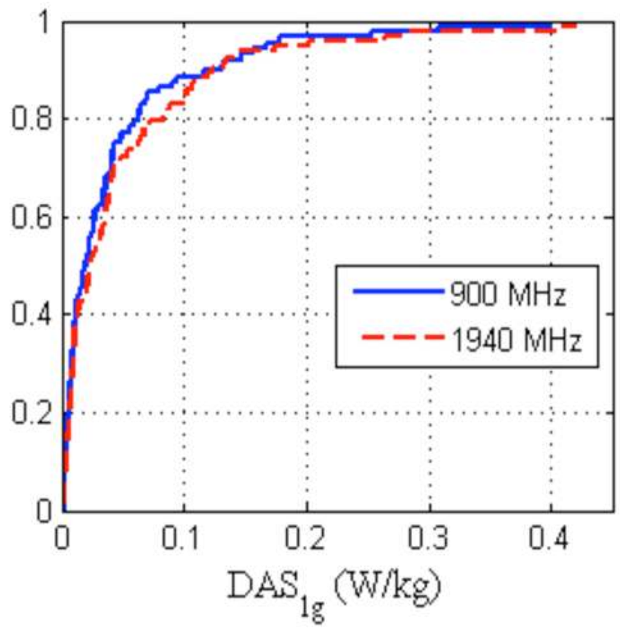
- 4 inputx

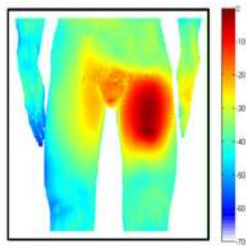
	Z	θ	φ	Δd
Intervalle	3±122	[-90° 60°]	[0 360°]	[1 10 mm]

.









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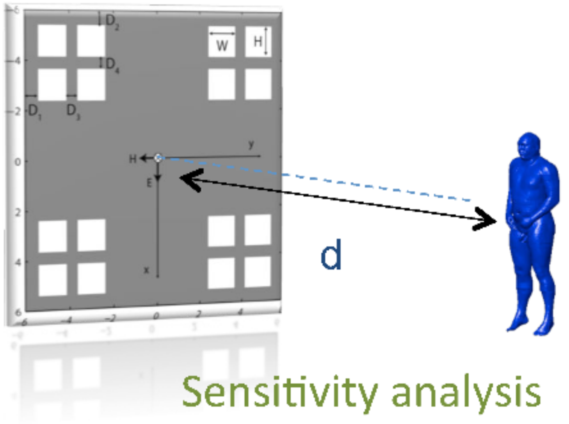
Supervisors O Picon and J Wiart

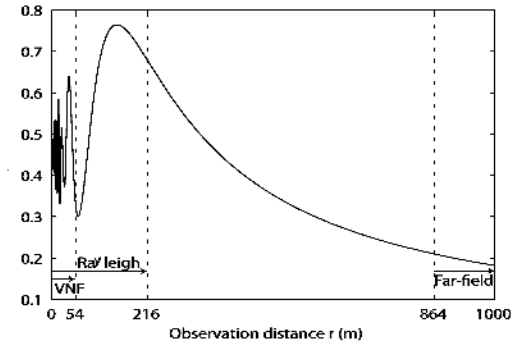
Exposure from reflection on wall



- 9 inputs
  - concrete and glass permittivity
  - height and width of windows
  - distance between windows
  - distance between windows and edges

LHS

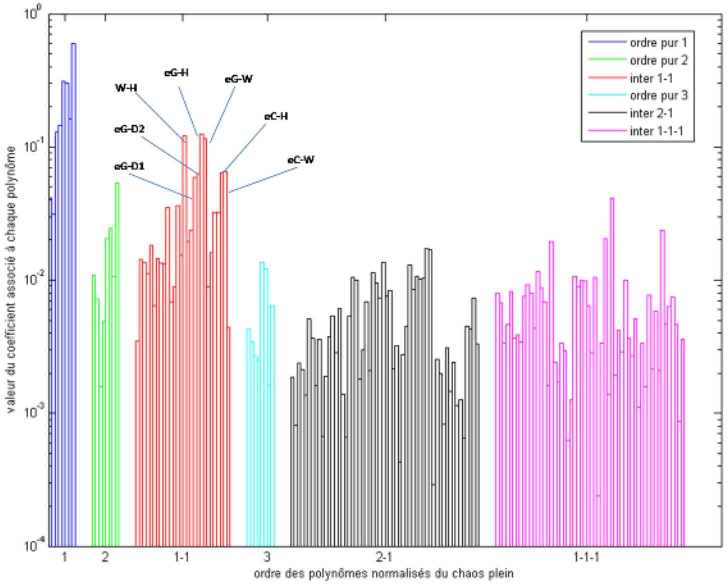
Deterministic approach



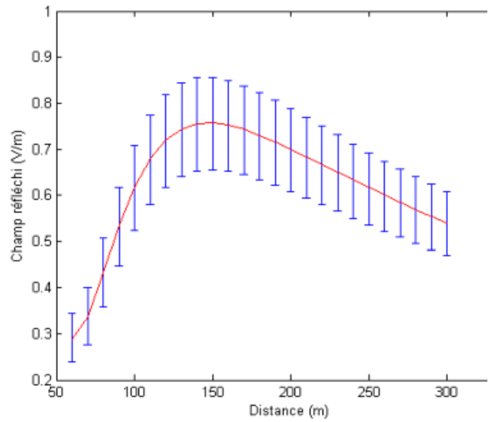
Sensitivity analysis

- Physical analysis: observation of the most inflent polynomials

- Prevalence of some interaction terms compared to the corresponding pure order terms



With PC



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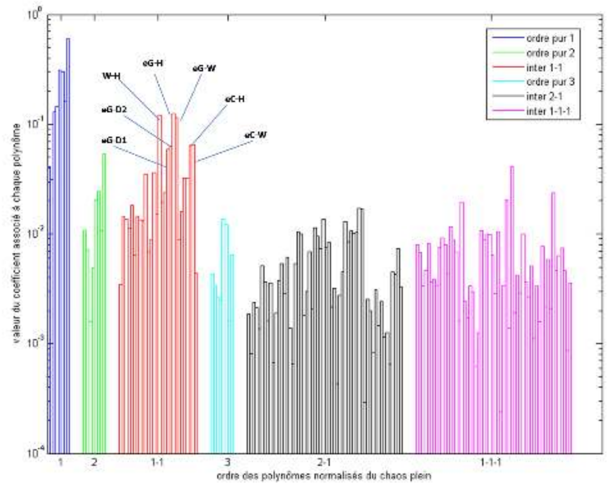
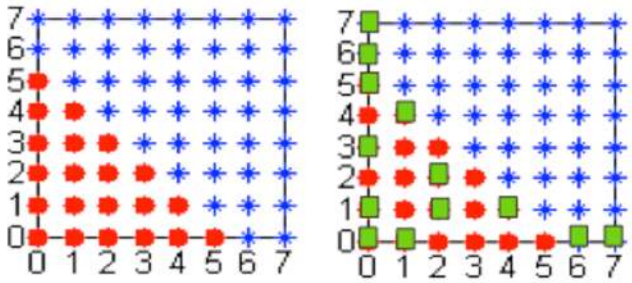
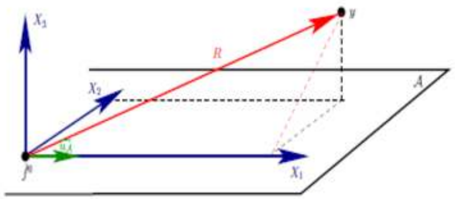
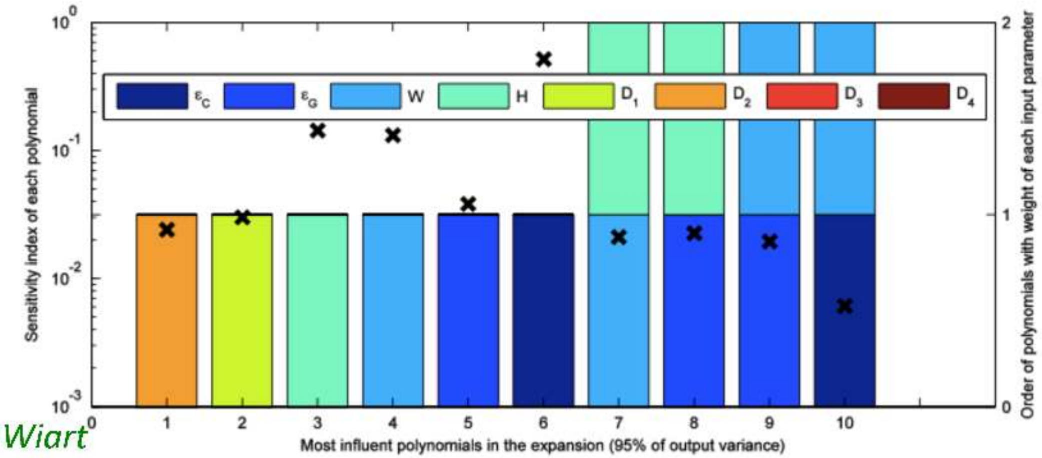
Limit the computationnal effort

- As shown in previous analysis all the polynomial are not playing the same role.
- How select relevant polynomials?









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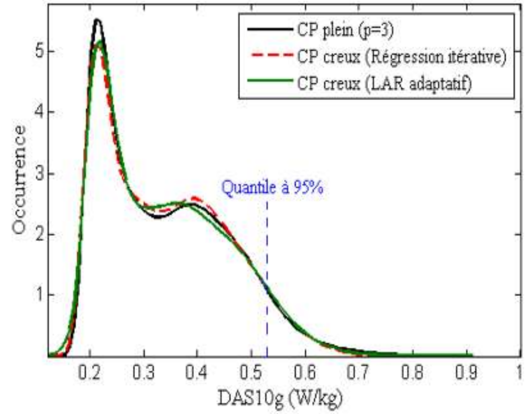
Least Angle Regression LARS

Sparse LARS truncation gives a significant reduction of the requested number of simulations

Next step : parsimonious iterative experiment for quantile estimation

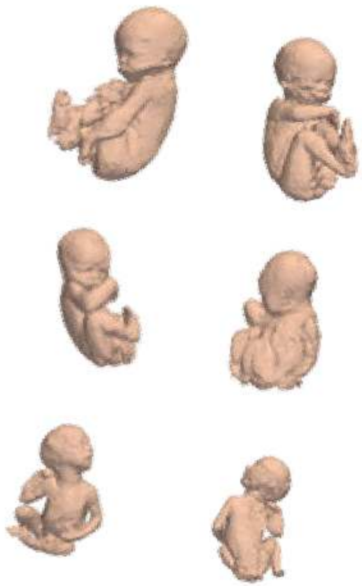


Most of the previous works were dedicated to built a surrogate model able to be used to characterise the shape of the distribution

But the exposure quantification often requests quantile estimation

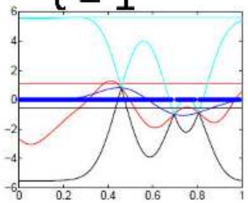
With the PC and the LOO the uncertainty of the surrogate model is mean square error

A challenge is therefore to built an iterative planning experiment able to monitor the uncertainty of specific quantile

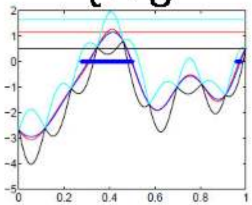


Fetus exposure Quantile estimation using Gaussian Process Shrunk (GPS)

t = 1



t = 8



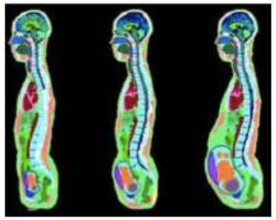
Phd works perfomed by M Jala

Supervisors : E Moulines, CLévy-Leduc, E Conil and J Wiart

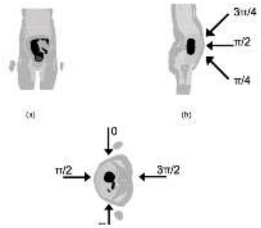
SAR in the brain of the fetus

GPS with gaussian kernel

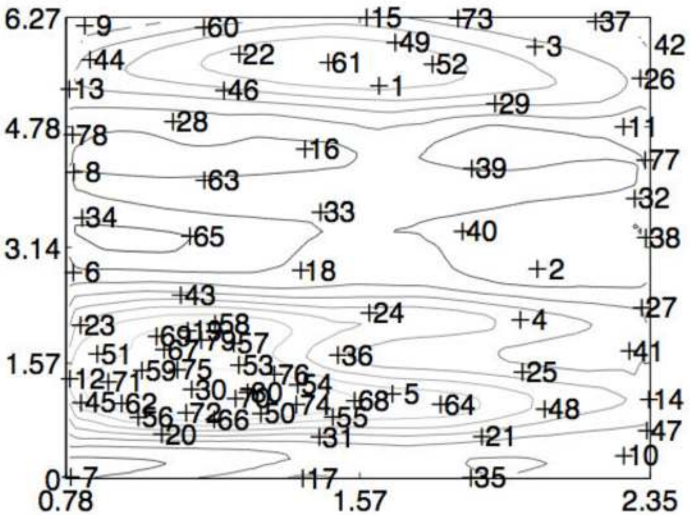
Heterogeneous model

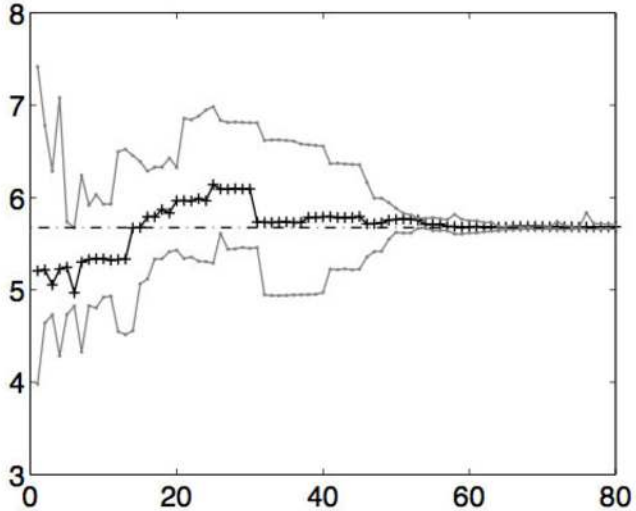


2 input parameters : angles of arrival



Sampling



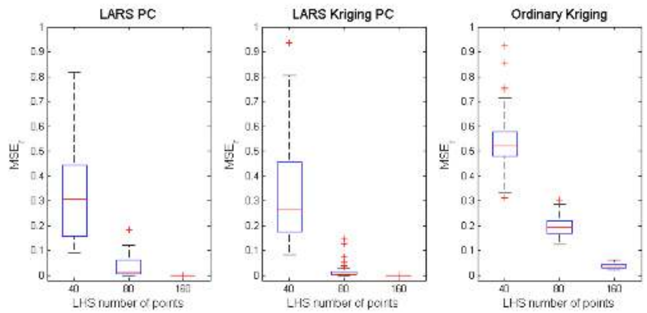


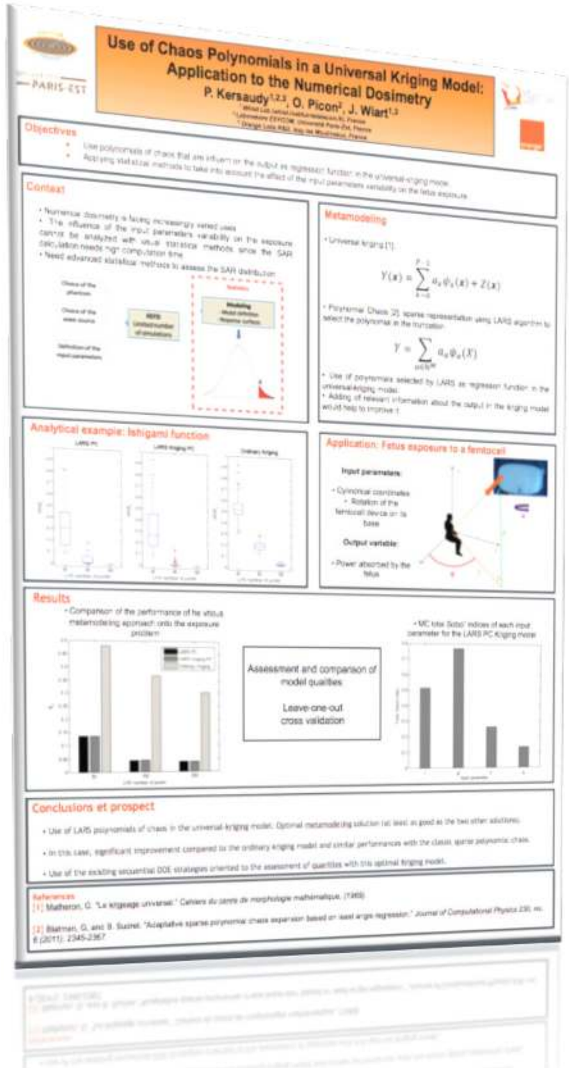
Quantiles vs iteration

On going :
Combination of Kriging with chaos polynomials

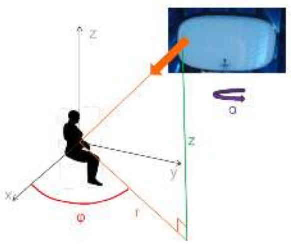
P. Kersaudy poster
in Mascott Num 2014

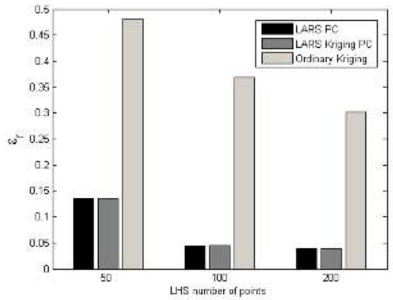
Result with Ishigami function





Application to
Fetus exposure induced by femtocell





Phd works perfomed by P Kersaudy

Supervisors O Picon, B Sudret and J Wiart

As Final Conclusion

Dans la confusion trouver la simplicité

De la discorde faire jaillir l'harmonie

Au milieu de la difficulté se trouve l'opportunité

Albert Einstein,

Trois règles de travail